Photovoltaic Cooker

Senior Project
Team Easy Bake
2016

December 11, 2016

Pablo Arroyo
pearroyo@calpoly.edu

Sam Beasley
srbeasle@calpoly.edu

Jeff Reeves
jmreeves@calpoly.edu

Advisor:
Dr. Andrew Davol

Mechanical Engineering Department
California Polytechnic State University
San Luis Obispo

<u>**Introduction/Background**</u>

Most Americans, like the mighty Bald Eagle or the cunning fox, love the outdoors. Camping and backpacking is an extremely popular way for humans to spend time getting in touch with their inner Thoreau. Although camping and backpacking is great, cooking food in the great outdoors can be difficult and have undesirable environmental implications. Campfires and propane camping stoves can be dangerous and they both leave a carbon footprint. With the decreasing cost of photovoltaic (PV) cells, it is now feasible to design a camping oven that only needs the energy from the sun to operate. Figure 1 shows how the price of photovoltaics have been steadily decreasing over the years. With this trend continuing, photovoltaic cooking will soon be a very inexpensive method of cooking. Using a PV cooker would leave no carbon footprint, and still have the power necessary to cook delicious meals.

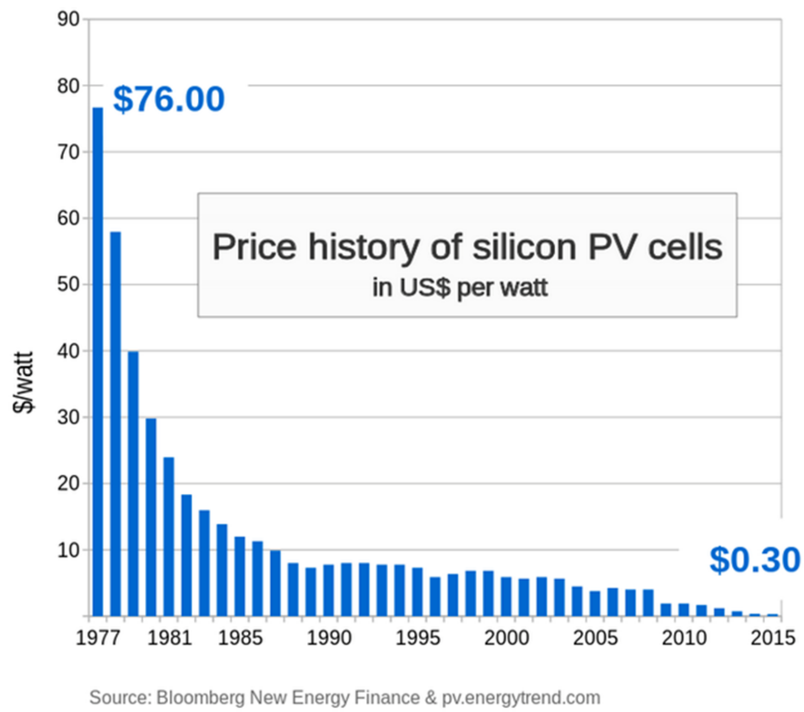


Figure 1. The decreasing cost of photovoltaic cells over time.

Source: Schwartz,Pete."PVE Cooking Presentation ME Jan 2016.pptx". 2016

There are already some products on the market that are attempting to reduce the carbon footprints of camp stoves. One of these products is called BioLite. Even though this product does not eliminate its carbon emission, it significantly reduced their carbon output. According to BioLite, their cooking stove has reduced particulate matter and carbon emission by up to 90%, it

uses 50% less fuel than a conventional open fire, and it cuts down 2.5 tons of CO_2 emissions a year. It also integrated a USB charger which can produce 2 watts of electricity, enough to charge a cellphone, from the heat produced. The total cost is around $130. A deeper analysis explaining the limitations of the product will be discussed further when compared to cooking with PV.

Another product with the same goal of building a portable camp stove is called JetBoil. JetBoil products use propane gas to cook food, and also have integrated control systems to control the heat. They have a variety of products ranging from $100 to $400. Each product has its own unique set of advantages depending on the requirements the camper is looking for. All have the capability of being portable and compact, and some products integrate a full camping stove with a pot for simmering/boiling or a pan for grilling, frying, or searing.

A third product we researched is called the GoSun Solar Oven. This device uses circular glass tubes with vacuum insulation to cook the food. The oven is heated using parabolic aluminum reflectors that focus the sun's energy on the tubes. Although it is large and bulky, this oven does not release any carbon emissions and can heat up to over 500 °F.

Lastly, a patent search was conducted using the United States Patent and Trademark Office.[3] There were several patents utilizing photovoltaic cells to cook food; however, all of them were used as hybrid systems. Most of these hybrid systems include a battery used to store the energy and release it whenever necessary. Our solar oven will not interfere with these patents. If we choose to go with a vacuum insulated design, however, we will have to be mindful of the manufacturing process we choose. There are multiple patents regarding methods of vacuum insulation, and we will have to work around these.

Objectives

Our problem statement is as follows:

"The goal of this project is to design and build a portable camping oven that is powered by photovoltaic cells."

Table 1. User Requirements and Engineering Requirements for our photovoltaic cooker.

Customer Requirements	Engineering Specifications
• Affordable • Effective/Practical • Can be used all year • Easily Assembled • Durable • Easy access to food • Safe • Compact Packaging • Environmentally friendly • Can cook for a small group of people • Way to utilize excess PV energy	• Requires <250 Watt solar panel • Costs less than $400 for all parts (including solar panel) • Boil a liter of water in <30 minutes • Assembled by 1 person in 10 minutes • Pressure should not exceed calculated yield strength • Operated by one person • Exterior temp does not exceed 110 °F • Minimum lifetime of 5 years • Contains USB charging port

Table 1 lists the customer requirements we hope to fulfill in our portable camp oven. Some of the more critical customer requirements are easily assembly, compact packaging, and being effective/practical for campers. Fulfilling these requirements along with using PV cells to harness the solar energy will set us apart from our competitors. Also, we listed out the corresponding engineering specifications to the customer requirement.

Table 2. Formal Engineering Specification Table

Spec. #	Parameter Description	Requirement or Target	Tolerance	Risk	Compliance
1	Cost	<$400	Max	M	A
2	Effective/Practical	Boil 1 Liter in 10 mins	Max	H	A, T, I
3	Size	1.5 cubic ft.	Max	H	T, I
4	Power Usage	<250W	Max	H	A, T
5	Assembly	1 person in 10 mins	Max	M	T
6	Long Lifetime	5 years	Min	L	A
7	Environmentally Friendly	0 CO_2 emission	Max	L	T
8	Safe	Exterior temp. not exceed 110°F	Max	M	A, T
9	Lightweight	30 lbs	Max	H	A, T

Table 2 is a table of our formal engineering specifications and how each requirement is to be verified. The three types of verification are either analysis (A), testing (T) or inspection (I). The

table also includes an assessment of the risks of meeting each of the engineering targets. The targets that are crucial to meet are given an “H” while the medium and low risk targets are given an “M” and “L” respectively. The three specifications that are going to be most crucial to meet in relation to risk are the cost, size and weight of our product.

The first main objective is to make an environmental friendly cooker as efficient and as practical as possible by conserving a considerable amount of energy. Hence, our first phase is building a PV cooker that can be utilized to cook food during a sunny day without carbon dioxide emissions. The PV cooker will have a target power of less than 250W through a solar panel, and we would like to convert at least 30% of the energy into active thermal energy for cooking. The 250W solar panel and a supplemental power supply will provide energy to the cooker bringing one liter of water to a boil within 10 minutes. We will then add a safety precaution by not having the cooker go over 500°F.

Our next objective is to find a way to utilize any extra energy produced by the photovoltaic cells. We plan on implementing a USB charging port that can charge electronics using this excess energy. The initial goal for our PV cooker is for it to be fully operational with a minimum of 4 hours of available sunlight. We are also designing our cooker to last a minimum of 5 years under normal operating conditions.

From our customer requirements and engineering specifications, we made a Quality Functional Deployment (QFD) diagram and it can be found attached in Appendix B. A QFD uses matrices to outline the customer requirements and their corresponding engineering specifications, comparing them to other related products. The customer requirements and the engineering specifications are then weighted against each other to show whether there is a strong, moderate, weak or no relationship between pairs. It also relates the engineering specifications to portray whether improving one specification benefits the other or if it's at the expense of another specification. Also in the QFD, we can evaluate our product with our competitors and show which requirements we should prioritize.

We found four alternative cooking methods to compare to our PV cooker in the QFD. Those four methods/products are BioLite, a portable solar concentrator, a Jet Boil stove, and a conventional wood campfire. Having these comparisons in the QFD showcase the advantages

and disadvantages of each product, which we will take into consideration when designing our PV cooker.

For a timeline of this project, please see figure 2 below for the gantt chart highlighting important deadlines.

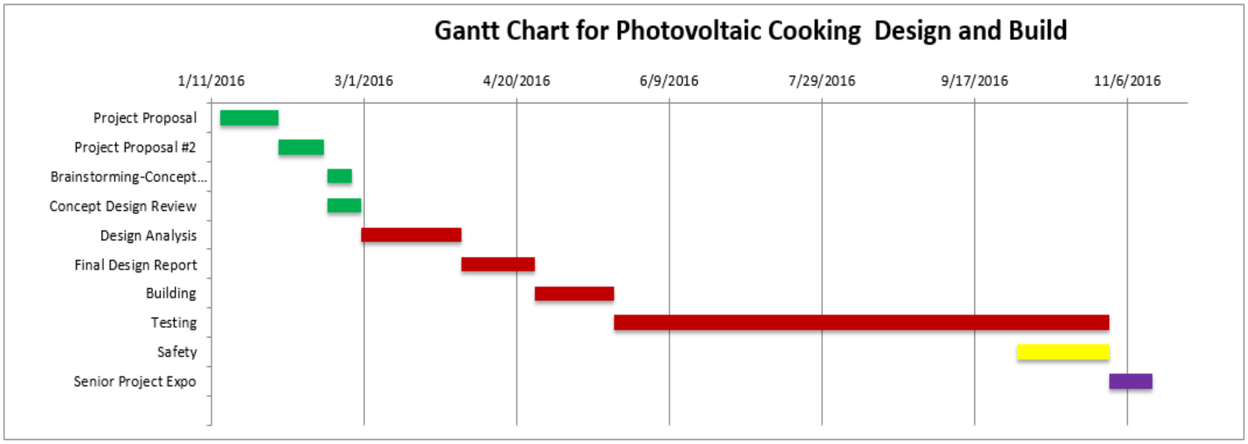


Figure 2. Gantt chart highlighting important milestones from the project initiation to the Final Design Report

Process of Choosing Our Lead Concept

In order to pick a finalized concept, we had to narrow down our broad range of brainstormed ideas. The main tool we implemented was a decision matrix. Figure 3 shown below is the decision matrix template we used. The top row of the matrix includes all of our brainstormed ideas, as well as a standard which is the most common idea already on the market. These ideas are measured against a list of criteria that needs to be met. The standard idea has a rating of zero for all of these criteria, and the other ideas are given a rating from -5 to 5 based on how well they will meet the criteria when compared to the standard. Due to the fact that some criteria are more important than others, each is given a weight from one to five. The rating of each idea is multiplied by the criteria weight resulting in a weighted score. These weighted scores are added and displayed at the bottom of the matrix. The ideas with higher weighted scores meet the criteria better than scores with lower scores.

Weighted Decision Matrix -

Decision Factors		Standard	Idea 1	Idea 2	Idea 3	Idea 4
Criteria	Wt.	1	2	3	4	9
Criteria A	2.0	0	1	3	2	4
Criteria B	4.0	0	1	1	0	-2
Criteria C	5.0	0	4	4	3	4
Criteria D	5.0	0	-2	-5	-4	0
Criteria E	3.0	0	2	4	-1	-1
Weighted Scores		0.0	22.0	17.0	-4.0	17.0

Category	
Criteria	Definition
Criteria A	Definition of Criteria A
Criteria B	Definition of Criteria B
Criteria C	Definition of Criteria C
Criteria D	Definition of Criteria D
Criteria E	Definition of Criteria E

Figure 3. Template of our Weighted Decision Matrix. `

We created four separate decision matrixes for the categories of insulation, portability, heating elements, and energy storage. These decision matrixes, included in Appendix C, highlighted the good and the bad aspects of each idea. Using these matrixes was a good way to rank our ideas based on how well they met important criteria.

Once the decision matrices had been made for the four main components of our design, we did another brainstorming session using the top three decision factors from each decision matrix. For this final brainstorming session, we each came up with a concept design using the top three decision factors and drew it on the whiteboard. Each person picked the components they would like to incorporate into our final design and circled it on the whiteboard using a different color to differentiate between each other's concept designs. After we selected the individual components, we sketched our ideas under the column labeled "pictures" as shown in figure 47.

With each of our concept designs drawn, each person presented their design and discussed how they plan on integrating each component they selected. This was followed by another group discussion where we pointed out the pros and cons of each design.

The first design we came up with was a vacuum insulated “thermos cooker” which stores energy using a battery and phase change material (as shown connected by the orange line in figure 5. This thermos cooker would likely be used for recreational backpacking or fishing/hunting trips. A large inspiration for this design came from the Hydro Flask water bottles and their ability to keep drinks at the desired temperature for a long time. The thermos cooker would likely have the heating element built into the lid with a small battery that can be discharged to give the device an extra “boost” to heat the food. Also inserted in the lid would be some type of thermal storage. The battery would give the device an initial boost of power which would then be maintained by the thermal storage. By connecting a microcontroller, the PV and the thermal storage will work in tandem to maintain a constant temperature and use as little power as possible. The main advantage of this design is that it is portable. We would likely use a flexible photovoltaic panel that the user can drape over their backpack and charge the cooker while they hike. If desired, the user can also use the direct energy from the PV to cook their food (or boil their water) while hiking.

Another design we considered was a type of collapsible oven that closely resembles a pop-up tent. The point of this design was to have a camping cooker that is compact and can also expand to fit larger portions of food. Our inspiration for this design came from pop-up laundry hampers and garbage baskets that some of us own. This design includes a rigid circular bottom section that holds the heating device while the insulation would likely be made from a microporous material or a ceramic fiber. The insulated portion of the device where the food is cooked would be able to collapse for easy packaging while the photovoltaic panel is connected to the cooking portion.

We have also been exploring the possibilities of making a portable stove that can be used for car camping. We realize that a large number of Americans enjoy car camping and there is a larger market than for backpacking. For this reason, we have not specified the type of camping we are going to tailor our oven towards. Our first idea for a car camping oven was to make a two-piece cooker that has a removable lid for easy storage. The lid portion of the cooker is

much like you'd find on any conventional barbeque except it is in a rectangular shape. Sketches of this design can be found in figure 50. The design would include heating coils in the bottom of the device and a steel grate which the food will be cooked on. This oven would also include a section for "hot rocks" on a grate above the heating coils. The user would be able to insert fist-sized rocks into the cooker to be used as a free source of thermal storage. After the heating coil heats the rocks to a certain temperature, the rocks will continue to radiate heat and reduce the amount of power required by the photovoltaic panel to cook the food.

Adding onto the previous two-piece car camping cooker, we also came up with the idea of having a cooker with a "drawer" built into it. The purpose of this drawer was to be able to check on your food without opening the lid and letting all that heat escape. It would also be ideal if the user was cooking small portions of food where they could insert their meal only through the drawer. This would allow the user to preheat the oven and insert their food without losing too much heat to the environment. The lid would still be removable to allow for easier storage, as well as give the user the option to lower their food inside the cooker if it does not fit through the "drawer". This lid will likely be vacuum insulated due to its simple geometry and it will be secured to the rest of the cooker via snap latches.

A final car camping design we came up with involves an oven that that turns into a chair. The user would sit on the insulated lid while the food cooks. A backrest can be attached to a solar panel that can be adjusted based on the position of the sun. The solar panel would also be attached to a pair of adjustable legs so the user can recline the chair and still be able to adjust the solar panel to face the sun directly. The legs would be able to pivot on an axis to fold underneath the solar panel. The solar panel and legs would then fold on the underside of the backrest, which would then fold on top of the oven. A sketch of this design with the folding motion can be shown in figure 51.

Final Design: Car Camping "Drawer" Cooker

The final design we decided to move forward with was the "drawer" cooker. This "drawer cooker is a solar powered, more practical spin off of a household toaster oven designed for car camping. This particular concept is a single oven with a pull out drawer instead of a conventional hinged door. The majority of this oven is made with 6061 aluminum due to its low

density and thermal conductivity and construction/testing of this design will be explained in the following section of the report.

The inside of the oven will consist of five sheets of 1/40” thick 6061 aluminum (top, bottom, right side, left side, and back) and will be enclosed by another aluminum frame. This frame will serve as a structural support because the inside walls of the oven are so thin. In case the user drops the oven, we want all the inner components to remain unharmed. Each side wall (as well as the back of the oven) will sit in place via grooves in the sides and top of the structural support. Each wall will have about 0.05” of “wiggle” room on each side to account for thermal expansion within the oven as it heats up. An assembly of the inner oven is shown in figure 4 below.

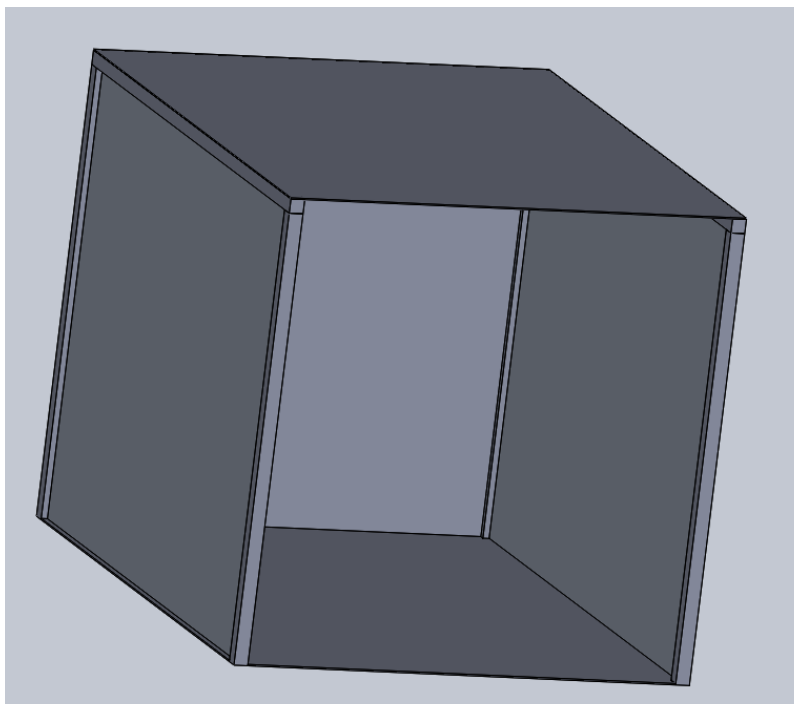


Figure 4: Assembly of the inner oven

Surrounding the inside walls of the oven will be half an inch of Microtherm quilted insulation. Microtherm is a microporous insulation which we chose due to its excellent thermal conductivity and density. Since this layer of insulation will be directly outside the inner walls of the oven, it is important that the insulation is relatively rigid which will protect the inner components if a large external force is applied by the user. There will also be two 2” x 1.25” blocks of plastic, which are flush with the front and back walls of the oven and surround the Microtherm insulation.

These blocks of plastic will be cut from a High Temperature UHMW Polyethylene sheet due to its high temperature resistance, good tensile strength and excellent impact strength. Properties of this plastic can be found in figure 55. Not only will these blocks serve as structural support, but they also serve as an anchor point to fasten the inside and outside walls of the oven. There will also be a thin sheet of 0.025” aluminum covering the Microtherm insulation between the polyethylene and inside wall of the oven.

Surrounding the Microtherm insulation (in between the polyethylene plastic supports) will be 1.5” of mineral wool insulation. We decided to choose mineral wool for this application because of its low price, thermal conductivity and malleability. Also, with the addition of the rigid plastic supports, it is no longer critical to have this middle set insulation be rigid which makes wool an ideal choice. Properties of this wool insulation can be found in figure 56.

The inner oven, Microtherm, wool, and polyethylene plastic will all be enclosed in five sheets of 15.34” x 15.3” x 0.025” aluminum (top, bottom, sides, and back of the oven). This aluminum enclosure will hide the insulation and serve as more structural support to the oven. The hard plastic, which is flush with the front of the oven, will still be open to the atmosphere and will be the contact face between the body of the oven and the drawer.

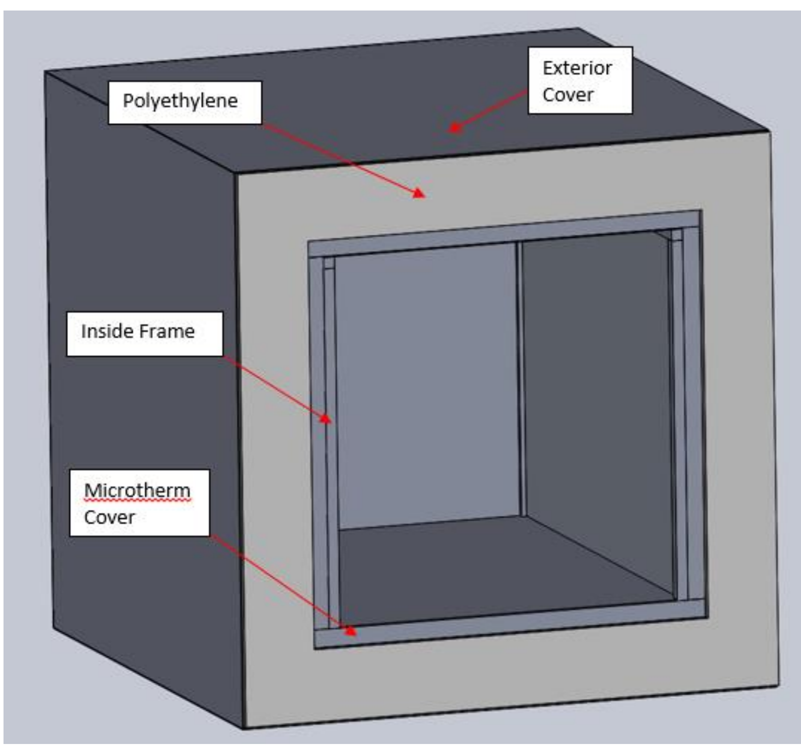


Figure 5: Assembly of the inner oven with outer walls

Much like a conventional oven door, the drawer mechanism of this design will replace the standard hinged door with a fully-extending sliding “drawer”. The face of this drawer will be similar to the body of the oven. It will consist of a 10.22” x 9.82” x 0.025” sheet of aluminum which is held in place via groves in a surrounding structural support (much like the inner walls of the oven body and aluminum frame). This frame will also be surrounded by ½” of Microtherm insulation and again by 1.5” of the High Temperature UHMW Polyethylene. Behind this Microtherm and polyethylene will be another 2” of the same mineral wool as in the body of the oven. The small layer of exposed microtherm will be covered in a similar way to the body of the oven (with a thin sheet of 0.025” thick aluminum). We did this to completely seal the insulation from the atmosphere. If the Microtherm were left uncovered, then it would be in close contact with the food when the drawer is open. The insulation is then sealed more 0.025” thick 6061 aluminum . In order for the drawer to slide freely, it will be attached to a pair of Accuride slides. The slides we decided to choose are corrosion resistant and can withstand high temperatures. For specifications about these slides, refer to figure 57. These slides will be attached to the face of the drawer by an “L” bracket that and it they will be attached to the inside wall of the oven with three #8 pan head screws. A solidworks drawing of these slides are shown in figure 6 below.

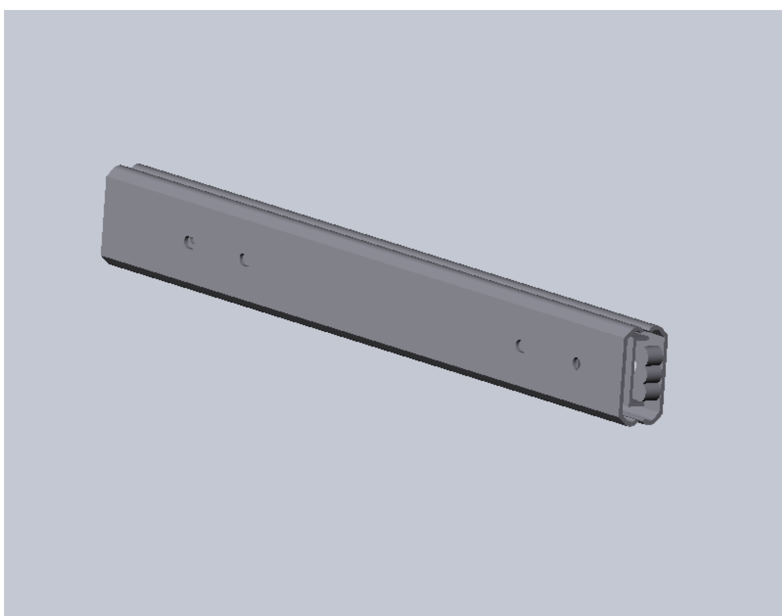


Figure 6: Accuride drawer slides

To add an extra layer of protection to these slides, we have added a grease protector. These protectors are made from thin sheet of aluminum and are flanged on the top and bottom. The top flange is to protect the inner parts of the sliders from food or any grease splatter that may occur during use. The bottom flange is smaller and will be used to hold the cooking grate. Much like a standard oven rack, the user will put their food on a cooking sheet, aluminum foil or a cast iron pan and place that directly on the oven grate which rests on the two flanges. These grease protectors will be attached directly to the drawer slides facing the inside of the oven. See figure 29 to see how they attach to the drawer slides.

This drawer design will act much like a conventional oven door and allow the user to place their food in the desired location on the oven rack without allowing all the heat to escape. It will be secured to the body of the cooker with a latch action toggle clamp while cooking. There will also be a rubber oven gasket on the inside of the oven where the body and drawer face meet to ensure a tight seal. Also, to ensure even less heat loss during cooking, there will be an added rubber gasket outside the existing oven gasket. When the oven is clamped shut with the toggle clamp, the drawer face and oven body will squeeze the two gaskets, making it much more difficult for heat to escape. Figure 7 below shows where these two gaskets will be placed in relation to the body of the oven.

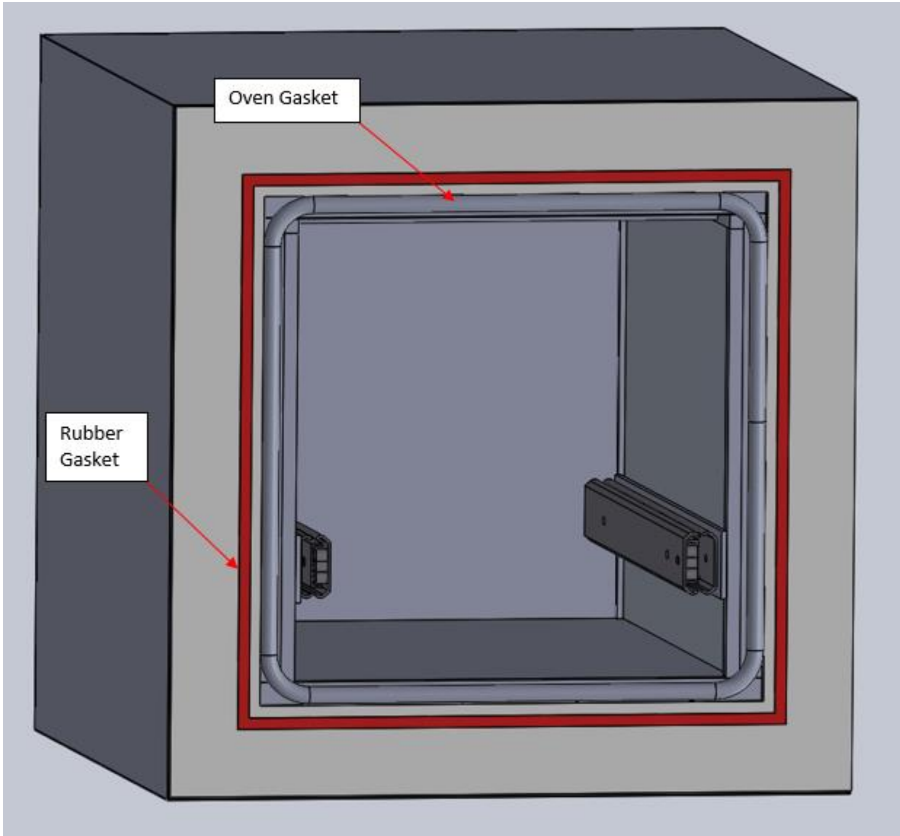


Figure 7: Oven body with gaskets attached

One important aspect of this design is the thermal storage unit. The purpose of the thermal storage is assist the PV panel in providing stored energy to the system, hence there will not be a dramatic change in the temperature due to opening the oven and interacting with the food. The concept of the “Drawer” photovoltaic cooker is that the user will assemble their oven once they arrive to their campsite, add their thermal storage into the oven, and turn it on. Therefore, later in the day the oven will reach the user's desired temperature and they can start cooking their food. The thermal storage will keep the oven at the desired temperature and the heat coils will add the heat absorbed by the food. For this design, we have decided to use two small blocks (3” x 6”) of concrete and place them at the bottom of the cooker. This device will also work well for slow cooking applications where the user can put their food in the oven before preheating and cook the entire time with the assistance of the thermal storage. This is ideal when a longer cook time is desired while using as little power as possible. The photovoltaic panel will supply current through the heating coils which will give off heat and warm up the thermal storage device. As the thermal storage mass rises in temperature it will retain a large

amount of heat. After the heat source is turned off, the thermal mass will radiate heat to the insulated portion of the cooker and cook the food. This enables the heating element to stay off for longer, resulting in more power being redirected to our energy storage system. The thermal storage device can also be removed for a faster, more intense style of cooking.

We will also implement a control system and a thermocouple into our device that will monitor the temperature of the oven and determine whether or not the photovoltaic panel needs to be supplying power to the heat coils. For this design, we have decided to use an Arduino Uno with a 10-amp relay due to its ease of use and low price. The wiring from the Arduino will be threaded through a small hole drilled in the top rear of the oven to connect to the positive and negative leads of the Nichrome burner. We will also purchase a 16 x 2 character LCD display module and wire it to the Arduino. This LCD display will allow us to preset a desired temperature rather than simply displaying the current temperature inside the oven. A wiring diagram of this Arduino and LCD display is can be found in figure 45. We will put the end of the thermocouple at the top of the oven in order to get the most accurate reading for temperature throughout the entire oven. The Arduino will allow the thermal storage and the photovoltaic panel to work in tandem to maintain a constant temperature while using as little power from the PV panel as possible. We will also be implementing a USB port so that when the PV panel isn't being used to heat the cooker, it can charge the user's electronic devices.

This is our vision for this product: As you're sitting on the beach looking at the waves, you decide to prepare lunch before suiting up and going out in the water. You attach your solar panel to the roof of your 1975 VW camper van and plug in the bottom portion of your solar oven. Next, you place half a pork tenderloin on the oven racks in a baking dish and clamp the lid shut. You set the temperature to 350℉, plug in your phone and go enjoy the surf. After a two hour surf sesh, you come back and open the drawer to check on your food. The meat is cooked perfectly and your phone is fully charged. Life is good.

Meeting the Specifications:

Table 3. How our design meets the customer needs for the drawer cooker

Customer Requirements	**How it meets Customer Requirement**
Affordable	We will use stock materials and efficient manufacturing to keep the price affordable for our target market.
Effective/Practical	This concept cooker will be able to cook a range of different foods in an efficient and environmentally friendly way, appealing to many campers.
Can be used all year	Whenever there is sun, our solar panel will be able to capture enough sunlight to power our cooker.
Easily Assembled	Besides attaching the solar panel to the cooker, this concept does not require any additional assembly.
Durable	The cooker will be made out of sturdy metals that are made to last. All sensitive electronics will be well shielded from heat.
Easy access to food	The slide out drawer aspect of the design makes the food very easy to access.
Safe	Like any cooking device, users will need to be safety conscious when making food. A bonus of the drawer aspect of our design is the fact that it separates the user from the heat source when accessing food. The inside of the drawer will be hot, but with proper precautions and common sense there are no unique safety concerns.

Table 4. How our design meets the engineering requirements for the drawer cooker.

Engineering Specifications	How it meets Engineering Requirement
Requires <250 Watt solar panel	Our design will implement a 100 Watt solar panel
Costs less than $400 for all parts (including solar panel)	This design does not require any exotic materials/electronics that will spike the price. We will carefully choose materials that minimize cost while maintaining function.
Boil a liter of water in <30 minutes	After performing initial heat transfer calculations included in Appendix E, we theoretically estimate that this requirement will be met.
Assembled by 1 person in 10 minutes	Besides attaching the solar panel to the cooker, this concept does not require any additional assembly.
Pressure should not exceed calculated yield strength	With the robust materials chosen for this design, failure due to excess pressure will not occur.
Operated by one person	This concept was designed to be easily operated by a single person.
Exterior Temperature does not exceed 110 F	The exterior temperature will remain below 110F
Minimum lifetime of 5 years	The cooker will be made out of sturdy metals that are made to last. All sensitive electronics will be well shielded from heat by long lasting insulation.
Contains USB charging port	We have designed a USB port into this concept.

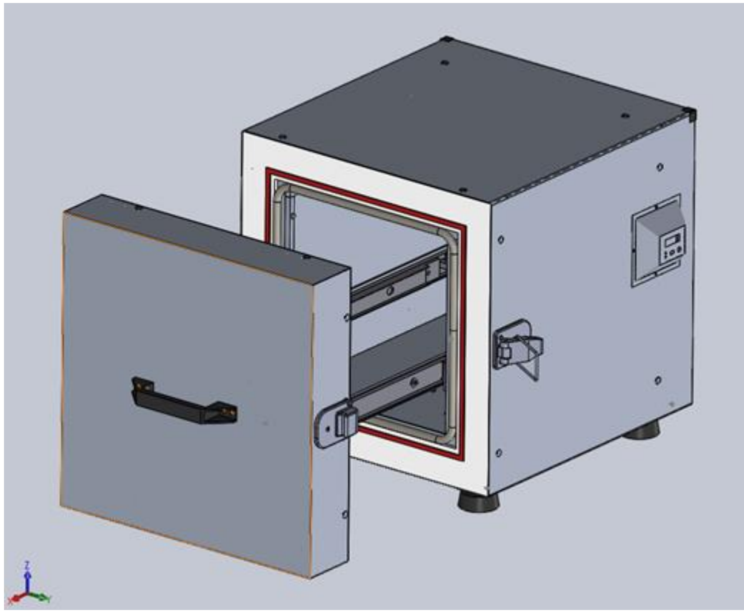


Figure 8. The final design of the photovoltaic cooker using SolidWorks.

A detailed construction of our final design can be seen in Appendix L. Appendix L goes over each of the components in detailed, and the process used to manufacture each component. Also, the bill of materials for our final design can be see in Appendix M.

Testing of Final Design

In the next few weeks, we will begin testing this design after the body has been built. Table 5 below shows our testing plan including which tests will be performed, what measurements will be taken from those tests, and what we will gain from each test. We have already obtained two thermocouple from Dr. Thorncroft for our testing phase and we have talked to the EE department and gotten their permission to use the high power DC power supply in room 106A of the EE building.

Table 5. Test plan for final design

Test to be performed	Measurements Taken	What we will gain
1. Supply 100W of power to nichrome wire 2. Wait for oven to preheat	● Preheat time ● Time it takes for temperature to drop 10	● Verify our calculations accurately model physical results

to 350 degrees F 3. Turn off all power and wait for oven to cool	degrees after power source is removed	● Preheat and temp. loss times under ideal conditions
1. Repeat above test, but include thermal mass	● Preheat time ● Time it takes for temperature to drop 10 degrees after power source is removed	● Verify our thermal mass calculations are correct ● Determine the usefulness of including the thermal mass
1. Still using the power supply, preheat oven to 350 degrees 2. Insert liter of water and wait until boiling	● Temperature of oven throughout process (including opening and closing drawer) ● Temperature of the water as it approaches boiling ● Time it takes for water to reach boiling	● Verify our "boiling water" calculations ● Determine temperature lost during the drawer open/closing process ● See if the time it takes the water to boil is reasonable
1. Hook 100 W solar panel to nichrome heating wire 2. Repeat the first test using solar panel midday 3. Use multimeter to capture current data	● Preheat time ● Current profile	● Capture the current profile for a real life photovoltaic cell ● Preheat times for actual photovoltaic

Necessary Equipment for Testing

- Type K Thermocouple
- Thermocouple temperature reader
- Power Supply (can provide at least 100W of power)
- Multimeter for current and voltage measurements
- Functional Prototype with all necessary components

Safety Considerations

Due to the fact that our product is a hot oven, there are several safety considerations that must be considered:

Major Safety Considerations

- Outer walls and handle/latch temperature must remain under 110 F to prevent burns. This is accomplished through proper insulation selection.

- Steam and pressure buildup can result in hot steam exploding out of the oven when the drawer is opened, possibly burning the user. To counter this, we have designed a steam release valve to allow the steam to leave the oven without harming the user.
- Extreme pressure buildup in closed oven could result in the oven exploding. With our operating temperature range, however, the pressure will never reach "exploding" pressure. Our oven will easily be able to handle the pressures it will experience.

For a more in-depth explanation about protecting against failure modes, please refer to the DFMEA table in Appendix I.

There are several maintenance and repair issues that we have considered. The main maintenance to be done with our oven will be cleaning. Due to the messy nature of cooking food, every internal feature will be removable for easy cleaning. The thermocouple temperature probe will also be easy to access just in case it gets dirty as well.

Our oven was designed to be as simplistic as possible. If any repairs are necessary, all of the components can be removed with no more than screwdrivers and wrenches. The majority of the components are easily replaceable and can be found online. If the Arduino breaks, the user will have to remove it and ship it to our manufacturing plant for a replacement.

Analysis

<u>Heat Loss</u>

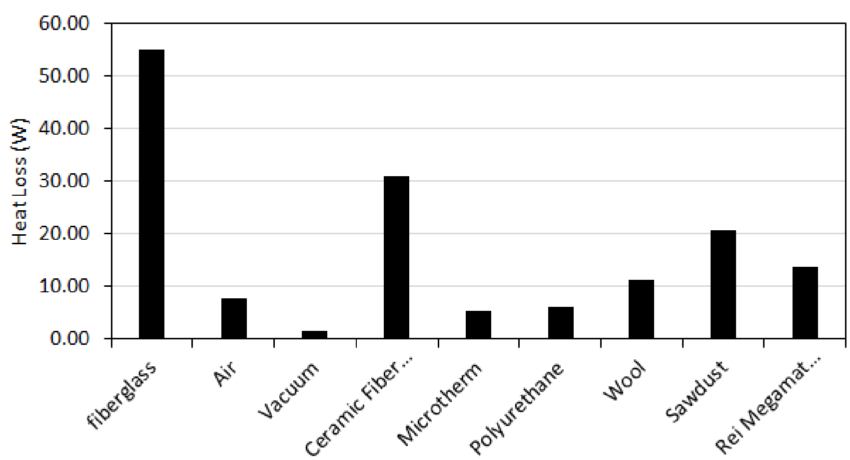


Figure 9. Bar graph of a 1-D Heat Loss calculation of various types of insulations

Figure 9 portrays the amount of heat loss from a given insulation. The longer bars signifies a larger heat loss and the shorter bars are the better insulators. The general equations used to solve for heat loss are Equation 1 and Equation 2.

$$q = \Delta T/R \quad (1)$$

$$R = L/KA \quad (2)$$

q represents the heat rate, ΔT is the change of temperature, and R is the resistance of the material. To calculate resistance Equation 2 was used. L is thickness of the insulation, K is the conductivity of the material, and A is the surface area at which the we are calculating the heat loss through. In this calculation, the resistance of steel was ignored since it has low conductivity and the heat loss due to radiation was ignored since the insulators have a low emissivity. The surface area, thickness and change of temperature were all kept constant at 100 square inches, 1.5 inches, and 275°F respectively. Lastly, from this graph we are able to visualize which insulators were the better insulators.

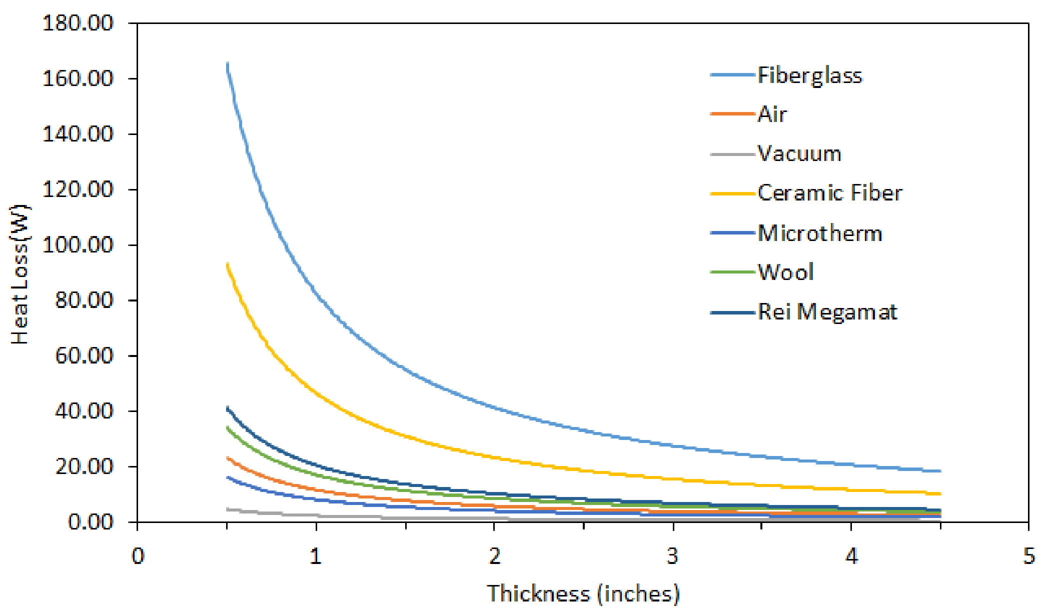


Figure 10. Portrays the heat loss of various insulators at variable thicknesses ranging from 0.5 to 4.5 inches

From Figure 10, we were able to establish the optimal thickness of insulation needed to have the lowest amount heat loss. It was establish that the optimal thickness is right before the graphs begin to reach an asymptote. For these insulations, most insulators begin to reach an asymptote between 2 and 2.5 inches. Therefore, it was decided the best thickness to give us the best results using the least amount of insulation was 2.25 inches give or take a quarter of an inch. For this calculation, the surface area and change of temperature were kept constant.

<u>Target/Stored Energy</u>

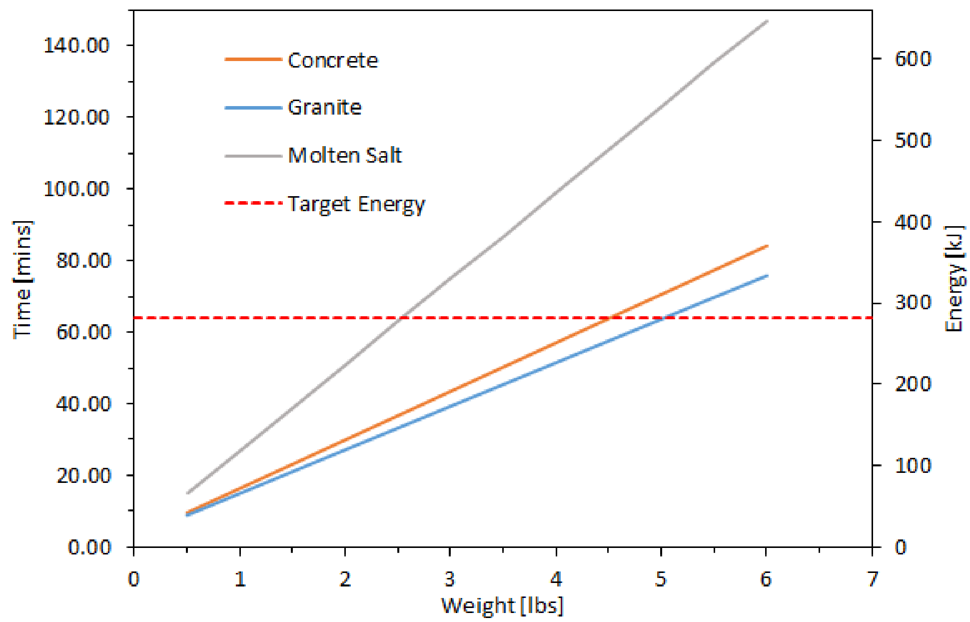


Figure 11. This graph portrays the weight potential thermal storage for the PV cooker versus the energy it stores from 212°F to 400°F and the time it takes to reach that temperature with the use of 100W. Also the red dash line depicts the target energy desired.

To calculate the target energy, we used the requirement of boiling 1 liter of water in 10 minutes. The boiling temperature in this case is when the water temperature reaches 212°F. The energy was then calculated for the water using its specific heat, Equation 3 was used.

$$Q = m * c * \Delta T \tag{3}$$

Q is the amount of energy, m is mass, c is the specific heat, and ΔT is change of temperature. The total amount of energy needed to heat up the inside of the oven included the water, aluminum frame, and the steel grate. This came out to be about 340 kJ. Afterwards, the energy generated in 10 minutes by 100W was subtracted from the total energy. Therefore, target energy was calculated to be 280 kJ.

Afterwards, the energy stored by molten salt, concrete, and granite were calculate from 212°F to 400°F at various pounds. The energy was then divided by the power it is receiving. The time to heat up various weights of thermal storage to 400°F was then found and presented in Figure 11. From Figure 11, it can be deduced that approximately 3lbs of molten salt, 5.5lbs of concrete and 6lbs of granite needs to be heated for 80 minutes in order to reach the target energy. Some assumptions and neglections that were made was that it was not taken into account about the thermal diffusivity of the different materials, therefore, some materials will take longer to heat. Also, the specific heat changes with respect to temperature. This calculation is used only to obtain a rough estimate on the amount of time need to boil water in 10 minutes.

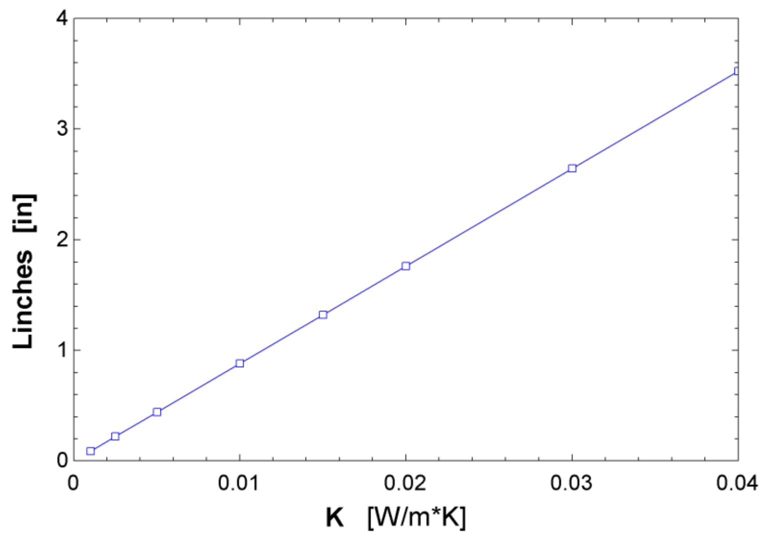


Figure 12. Portrays the conductivity versus thickness of insulation to keep the surface temperature of the oven below 104°F.

A sketch of the oven wall can be seen in Figure 6. Using Engineering Equation Solver (EES), the thickness of the insulation was calculated for varying thicknesses of insulation to keep the oven below 104°F. According to the ASTM C1055, the safe temperature to touch was 120°F;

however, due to the fact that the oven is exposed to people, the oven surface temperature will be kept below 104℉ corresponding to a tingling, very warm sensation to the touch. The code for EES can be seen in Appendix P. The worst case scenario was taken into account for this calculation, which was the inside oven reaching a constant temperature of 400℉ and the outside air was warm with a slight breeze.

From this graph, the required thickness for the insulation in use, Microtherm (which has a conductivity of about 0.25 W/m*K), is about 2.5 inches. Even though it was calculated to have a 2.25 inches insulation thickness to minimize heat loss, it will be required to thicken the insulation to 2.5 inches to satisfy the safety code for Product Safety Engineering. Cost will increase slightly, but in turn, there will be a better performance from the oven considering there will be a decrease in heat loss.

FEA Models

Three finite elements analysis were made using Abaqus CAD: one analyzing the stresses in the oven after applying a pressure, the other analyzing the thermal expansion of the oven, and lastly one analyzing the critical force of buckling for the rods.

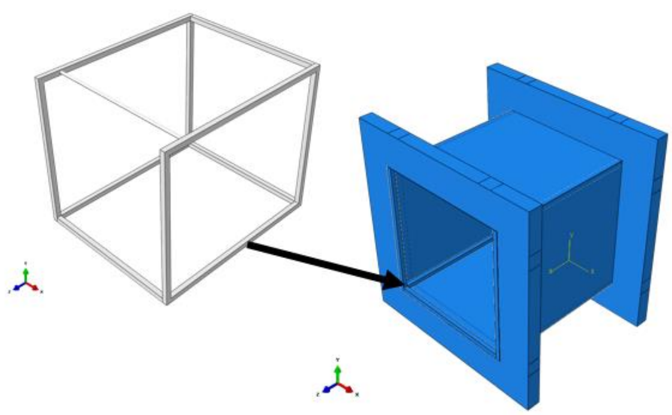


Figure 13. Portrays how the frame looks and where it is inserted in the assembly. Note the picture does not display the outer cover of the oven.

The oven was modeled as simple as possible in order to have a quality mesh. The frame, plastic supports, inner box and the outer box of the oven were created in SolidWorks. The .sat

files were imported from SolidWorks into Abaqus. It was then scaled down by a factor of 1000 to represent the all dimensions in meters. Solid, homogeneous sections were made for both the aluminum and plastic materials. The properties used are displayed in the table below, Table 7. Note the properties were all inserted a in the metric system, therefore, the results were given with metric units. However, to keep the consistency of English units with our SolidWorks model and having a grasp of what are results mean, the results were then converted to English units.

Table 7. Material properties of aluminum and plastic

	Material Properties		
	Aluminum	Plastic	
Density	270	930	[kg/m^3]
Modulus of Elasticity	68.9	0.86	[Gpa]
Poisson's Ratio	0.334	0.46	[-]
Thermal Conductivity	167	0.421	[W/m-K]
Thermal Expansion	22.2	1006	[x10^-6 m/m-K]
Specific Heat	0.896	1900	[J/kg-K]

The first model was built to analyze the stresses and deflection on the oven if a 100 lb force was distributed along the surface of the oven. All parts were meshed with a seed size of 0.01 corresponding to a size of 10mm. With all the parts mesh, the number of nodes totaled 37151 and the number of degrees of freedom is 111453. The element type used was C3D8R (an 8-node linear brick, reduced integration, hourglass). A static analysis step was then applied to the analysis. The tie constraint was use to tie the parts together. Also the plastic supports and the outer box of the oven were partition and constrained to mimic the screws. The bottom of the oven was fixed. The pressure to the top of the surface was then applied. Figure 40 shows the boundary conditions and the pressure force.

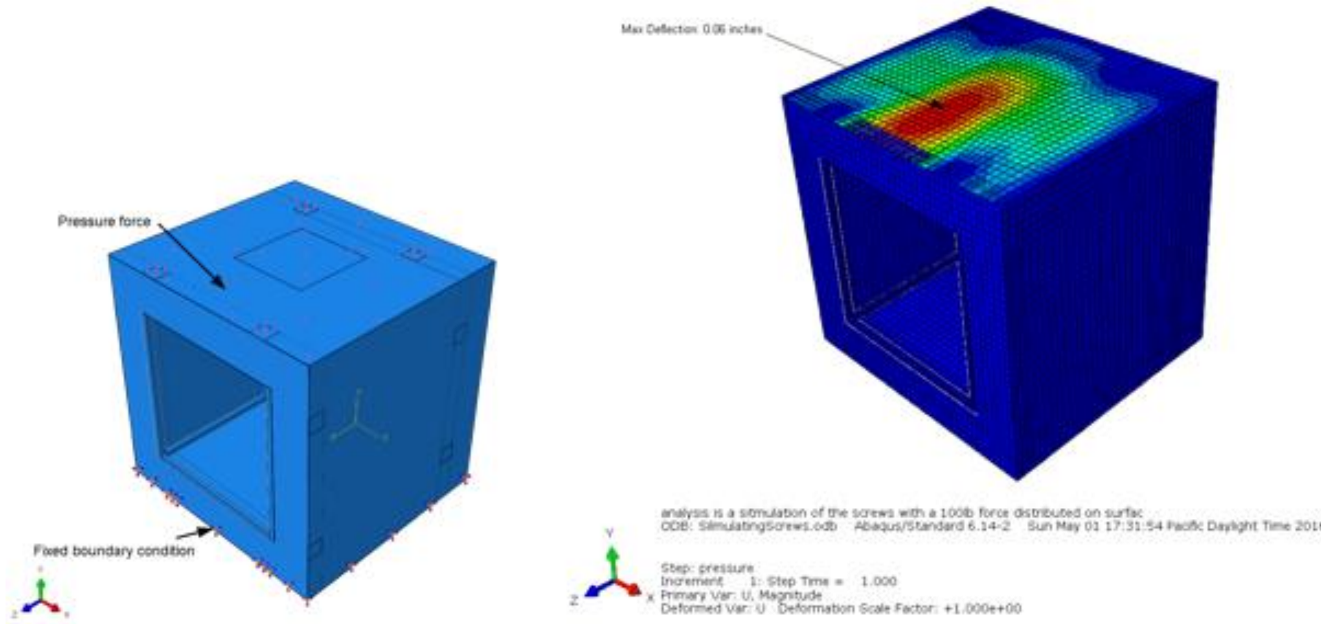


Figure 14. The left picture displays the forces and boundary conditions applied to the oven. The right picture displays the magnitude of the deflection.

The max deflection was 0.06 inches. The max von mises stress was 2200 psi. The high stresses are located at the edges of the top surface of the oven. All stresses are well under the yield tensile strength of the material, which is at 45 ksi. Therefore, it was determine the model design was suitable for the purposes of this oven. Also, this model does not depict the insulation which will be compacted in between the inner box and the outer box of the oven; therefore, the insulation will also aid in supporting the structure.

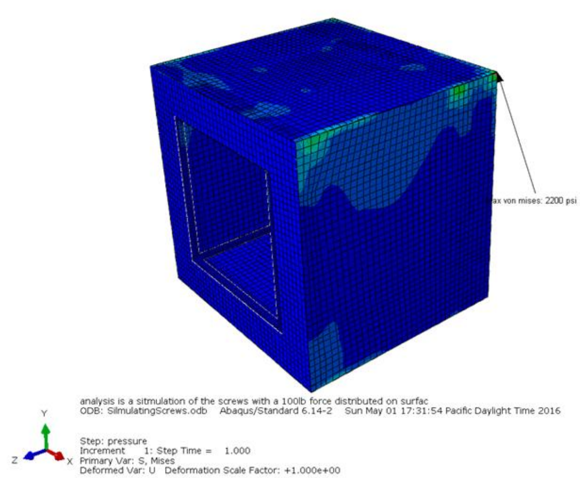


Figure 15. Displaying the von mises stresses on the outer box of the oven.

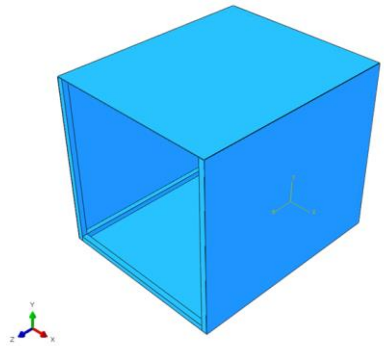


Figure 16. Portrays the assembly for the thermal expansion analysis.

Afterwards, a thermal expansion analysis was done of the inner frame with the inner box, as shown in Figure 16. Similar to the first analysis, all parts were meshed with a seed size of 0.01 corresponding to a size of 10mm. With all the parts mesh, the number of nodes totaled 14958 and the number of degrees of freedom is 59832. The element type used was C3D8T (an 8-node thermally coupled brick, trilinear displacement and temperature). A heat transfer analysis step was then applied to the analysis. The tie constraint was use to tie the parts together. The whole oven was then given a boundary condition of 400°F, the max temperature the oven can reach, and with reference to the room temperature. Figure 17 shows the results for this analysis.

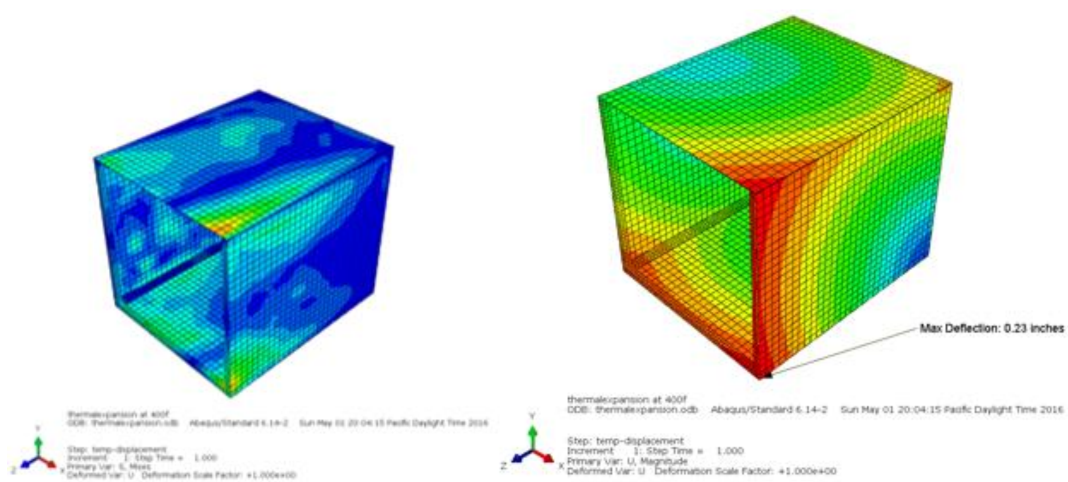


Figure 17. To the left, the picture is portraying the distribution of the von mises stress involved in thermal expansion. To the right, the picture displays the corresponding deflection caused from thermal expansion.

The max deflection from thermal expansion was 0.23 inches. The corresponding von mises stresses are not depicted since the model is not a true depiction how the inner portion of the oven will be fixed. The only concern was grasping a sense of the thermal expansion which will occur at the maximum temperature. The design will address this problem, since the panels are not welded to the aluminum beams, allowing for the aluminum panels to expanded. As for the aluminum beam, another FEA model was created to understand the stresses.

The buckling analysis was performed by creating a 5/16" by 5/16" by 10" rod. The number of nodes created was 2575 corresponding a 7722 degrees of freedom. The element type selected was C3D8R similar to the elements used in the first analysis. A linear perturbation for buckling analysis was used. Next, the rod was fixed on one end of the beam and a 1 newton force was applied to the center of rod. The first eigenvalue was then found, which was 183 lbs. From this value it was determine that the maximum load capacity of loading the top of the oven is 100 lbs.

Analysis of Pressure Increase

The ideal gas law was used for this analysis, Equation 4. The maximum temperature the user can set the oven to was used, which was 400℉ or 200℃. Using the ideal gas, it was calculated the pressure change will be 8.6 psi with respect to the room temperature of 75℉ or 25℃. Where P equals pressure, V equals volume in m^3, n is the number of moles, R is the constant, and T is the temperature of the gas in Kelvin. Equation 5 shows the simplified version of this equation which will be used to solve for the change in pressure. P_1 equals the starting pressure, V_1 equals to the starting volume, and P_1 and V_2 are the last state of the air.

$$PV = nRT \quad [4]$$

$$P_1V_1 = P_2V_2 \quad [5]$$

Afterwards, our team was concerned about the drawer of the oven launching out to relieve to pressure build up in the oven; therefore, a calculation was done finding the velocity of the air exiting the oven and subsequently finding the velocity of the drawer using a change of momentum. Bernoulli's equation was used to determine the velocity of the air. In this case, Bernoulli's can be used since only a short instant of time is being taken into account and only air is being analyzed, an incompressible fluid. Since, there is no elevation change and the velocity

at state one is zero Bernoulli's equation was modified, Equation 6. State 1 indicates the pressure of the air inside the air, and state 2 indicates the velocity of the air right at the exit of oven when it is initialing open, assuming the user did not open it beforehand.

$$P_1 = P_2 + \rho {V_2}^2/2 \quad [6]$$

$$m_1 v_1 = m_2 v_2 \quad [7]$$

The velocity of air was 70 ft/s at the entrance of the drawer. It will then dissipate into the surrounding before reaching the user. Therefore, a warning label will be place on the drawer suggesting for the user to take caution since the air coming out of the oven will be hot. However, the air coming out of the oven will not be harmful. It will only be an uncomfortable feeling for the user having hot air blown into their face. Using the momentum equation, Equation 7, the velocity of the oven was found to be 3.8 ft/s for the worst case, where the drawer has no added weight such as food or a tray. The momentum was calculated by solving for the mass of air, m_1,using the density of air, and using the previous solution for velocity, 70ft/s. Then a fraction of the mass of the drawer was used, m_2,and velocity of the drawer was then found.

Transient Heat Transfer Calculation Mode

A transient heat transfer simulation was created to estimate the amount of time our cooker will take to heat up 1 liter of boiling water. Two simulation were produced: one for our design, and one for the prototype. We used the following equations to calculate the transient modeling:

$$E_n[i] = E_{n-1} + (Q_{in} - Q_{loss}) * t_{step} \quad [8]$$

$$\Delta T = Q/((mC)_{h20} + (mC)_{mass}) \quad [9]$$

For equation 8, E_n represents the total energy in the system at a given timestep, E_{n-1} represents the energy at the previous timestep, Q_{in} is the power received (photovoltaic panel or power source), Q_{loss} is the heat lost in watts over the course of the previous timestep, and t_{step} is the change in time. The units of Q_{in} and Q_{loss} are in watts (joules/sec), and when multiplied by timestep in seconds, we can find the number of joules added to the system from the previous timestep.

For equation 1, ΔT is the change in temperature in kelvin between the in the inner and outer surface of the the insulation, and R represent the thermal resistance of the model. ΔT is found by manipulation of the specific heat equation, which is shown in equation 3.

For equation 9 a variation of equation 3, Q is the total energy of the system in kilojoules, m is the mass in kg, and C is the specific heat in KJ/Kg-K. The mass and specific heat variables are separated into 2 parts: water and specific heat. There are other various thermal masses in the system; however, they are negligible compared to the cement burner and water.

A MatLab code was produced to perform this transient model, see Appendix 2684318. The amount of energy present in the system is use to find the difference in temperature between the inside and outside of the cooker walls. This temperature gradient is then used to find heat loss in watts to the environment at that timestep. By subtracting the heat loss and add in the energy entering the system from the power source over the timestep, a new amount of energy in the system can be calculated. This calculation is repeated until the water reaches boiling temperature.

Electrical System

The electrical system was provided by Omar Arriaga, an Electrical Engineer from Cal Poly State University. An Arduino was selected as the microcontroller to communicate with all the other devices. Three thermocouples will be attached to the arduino: one monitoring the surface temperature of the oven, another relaying back the temperature of the oven, and the last thermocouple will monitor the inner temperature of any food. The thermocouple at the surface will be used as a safety factor, in case the outer walls reach a temperature above the 100℉ the Arduino will shut off the circuit. Another safety switch will be a bimetallic switch used for opening the circuit if the user leaves the oven on for a long period of time. The second thermocouple will be used and displayed on the LCD panel. The last thermocouple will be an optional use for the user so they may use it whenever they will like to monitor the internal temperature of their food. Figure 19 displays the breadboard diagram which will be the first iteration and also used for testing.

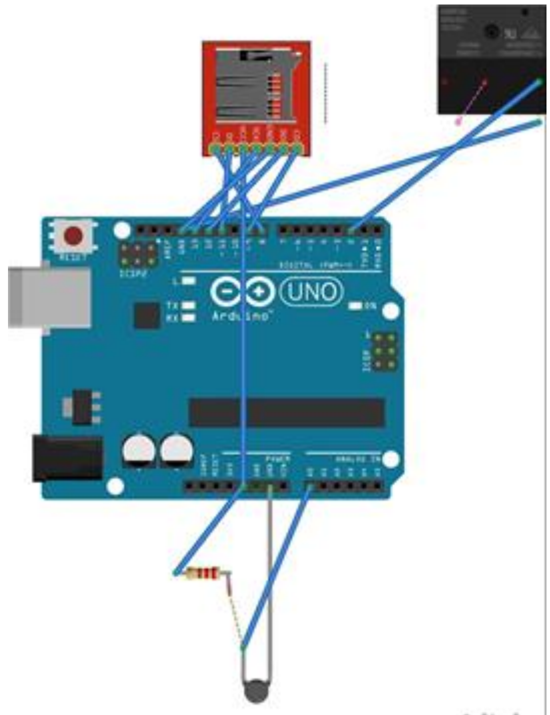


Figure 18. Arduino Uno with wired relay

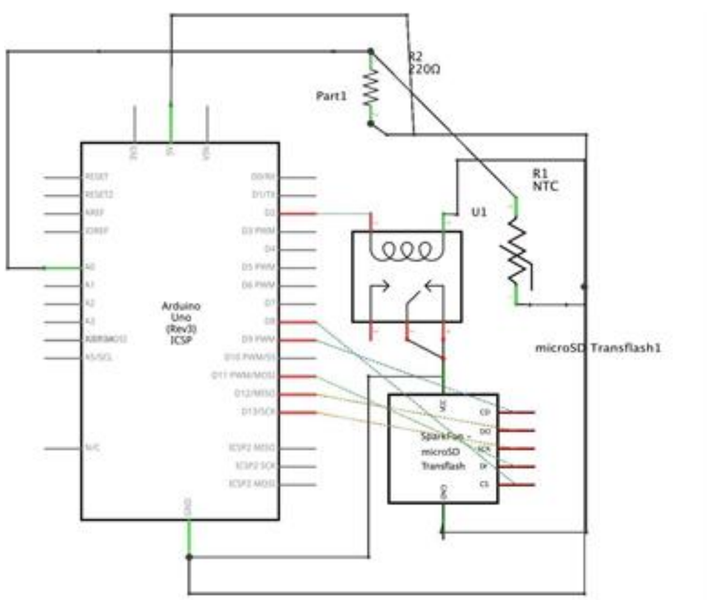


Figure 19. Wiring diagram of arduino with microSD and relay

Selecting the Nichrome Wire

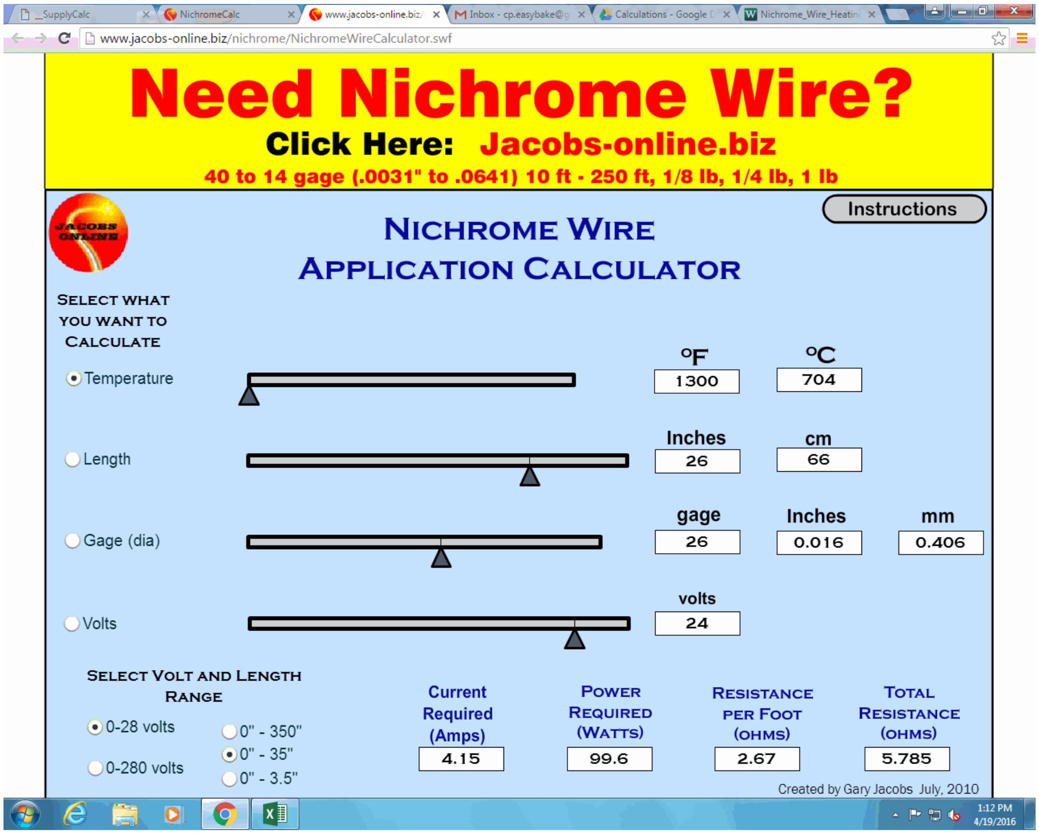


Figure 20. Nichrome wire calculator snapshot

To select the nichrome wire, the resistance of the nichrome wire was calculated by using Ohm's law, since it is known that the power is 100W and the voltage is 24V. A 26 gauge was then chosen from the manufacturer supplying the nichrome wire. The length was then found to be 2.17 ft. Once this was done, the numbers were entered into the calculator provided by Jacobs-online.biz. The maximum temperature was then found to be 1300°F. This temperature was then used for some of the calculations.

Construction of Prototype

For the construction of our prototype, we started by building the inner oven. This inner oven is comprised of eight pieces of galvanized sheet metal, which was purchased at Home Depot and spot welded together. Each sheet of metal came with the stock dimensions of 9" x 12" and two of them were bent to 90 degrees, half an inch in from the longest side. These two pieces are

used as the left and right sides of the inner oven. Since the metal sheets are only 9” wide, and we were trying to create a larger cooking area, we were forced to overlap the sheets on the top and bottom in order to complete the oven. The two pieces towards the front of the oven (the top front and bottom front) were bent 90 degrees, half an inch in from the 12” sides. These two 90 degree flanges will sit flush against the side pieces and will be spot welded together. Two more pieces towards the back of the oven (the top back and bottom back) were selected and a ½” x ½” piece was cut from two of the corners paralleling the 12” sides. This was done by using the sheet metal press in the Aero Hangar. After, three sides of the sheets were bent 90 degrees, half an inch from the 12” sides and half an inch from the 9” side. The two flanges on the long sides will sit flush against the sides of the oven, similar to the two front pieces. These two sheets will overlap the two front pieces to give the oven a total inside depth of 11 ½”. A final sheet will sit flush against the four flanges at the back of the box and will be spot welded to each one. The oven drawer was left as a blank sheet and was assembled later in the process.

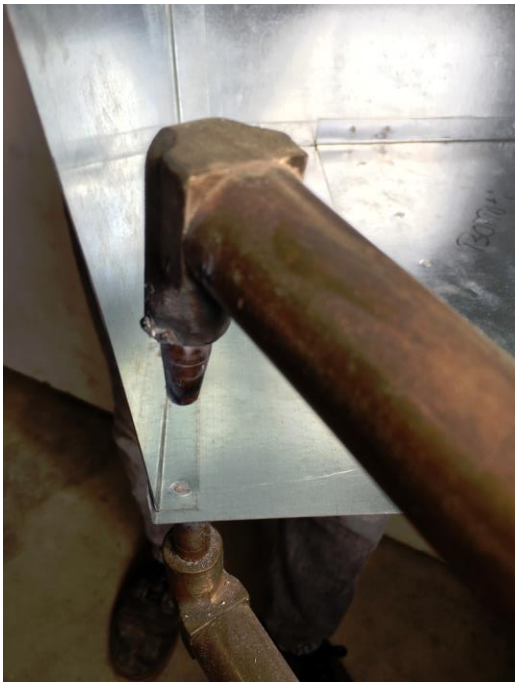


Figure 21. Spot welding the inner box together at the Hangar.

Figure 22. Completed inner box made out of galvanized steel.

The next step in assembling the prototype was to attach insulation. We took the large panel of Microtherm insulation and cut it into six panels (one for each side of the oven) with a ½" overhang on each side. The team then scooped out half an inch of the microporous insulation and re-stitched it shut to make the panels flush with the oven faces. The microtherm was glued to each face with JB Weld high temperature glue. Originally, the team was planning on using two sheets of Microtherm on each side. However, over summer break, the Mustang 60 shop techs accidentally misplaced some of it and we only had enough for one sheet on each panel. We bought a roll of R-13 fiberglass insulation and calculated the equivalent thickness for the insulation to be two inches. The inner oven with the Microtherm were wrapped in this fiberglass insulation and secured with more JB Weld. We were able to achieve a thermal resistance of 3.24 K/W compared to our final design resistance of 5.214 K/W. Adding anymore insulation to our prototype would had made our oven an inconvenience to transport.

Figure 23. Jeff “The Hammer” Reeves carrying our oven on a stick. Wooden plank was used to secure the insulation around the oven using a bungee cord.

After the insulation was added, the team then created the casing in which the oven and insulation are enclosed. The team obtained a large sheet of plywood and cut out two 14” x 16” pieces for the top and bottom, two 11” x 16” pieces for the sides, two 11” x 14” pieces for the front and back of the oven, two 11” x 3” pieces for the drawer sides, and two 14” x 3” pieces for the drawer top and bottom. The top, bottom, left, and right side pieces are secured together with two “L” brackets on each edge. Next, we put on the back panel and secured it with two “L” brackets on each edge (making a total of eight “L” brackets on back panel) and set the last 11” x 14” panel aside for the drawer. We then applied more JB weld glue inside the box and inserted the inner oven and insulation, making sure the glue was dried and the box was secure. The fiberglass insulation is not rigid and to account for this, we compressed it enough within the box so that the inner oven does not move.

Figure 24. Completed oven including the insulation, grill, burner, and wooden box.

The oven drawer was created by building the wooden shell first, then applying the insulation and inner oven lid. Using standard wood glue, the team was able to lay down the remaining 11” x 14” piece of plywood and glue along the edges of the 11” x 3” and 14” x 3” pieces. These pieces were glued the perimeter of the oven face to create the skeleton of the drawer. With a hollow box in place, we were able to cut and insert fiberglass insulation into the drawer. To create a rigid front oven panel, we used two pieces of scrap plywood (2 ½” x 3”) and glued them in the center of the drawer shell, spaced about two inches apart. We cut slits in the insulation in order to slide the wood pieces in and securely glue them to the wooden base below. After the glue dried, the front oven panel (with Microtherm) was then screwed onto the two wooden blocks.

Figure 25. The complete door for the photovoltaic oven.

Instead of hacking a burner, we decided to make our own out of concrete and nichrome. We created a 4” x 2” x ½” mold and ran a strand of 28 gauge nichrome wire through it. The nichrome was attached to copper wires at each end stuck through the mold. This is where we connect our power supply and solar panel. Next, we filled the mold with concrete and set aside until it hardened completely. After the concrete was cured, we were able to peel away the mold and remove the completed burner. After the burner was completed, the team drilled two ¼” holes through the back of the oven (one hole was drilled 1” up from the bottom of the inner oven while the other was drilled 1” down from the top of the inner oven). The copper wires were inserted through the bottom hole until the burner sat directly in the center of the oven, while the thermocouple was inserted through the top hole. The burner sits on top of a 8” diameter cooling rack so if any part of the nichrome wire sticks through the concrete, it won’t short circuit.

Figure 26. Mold used to make the cement burner in order to not have the nichrome wire exposed.

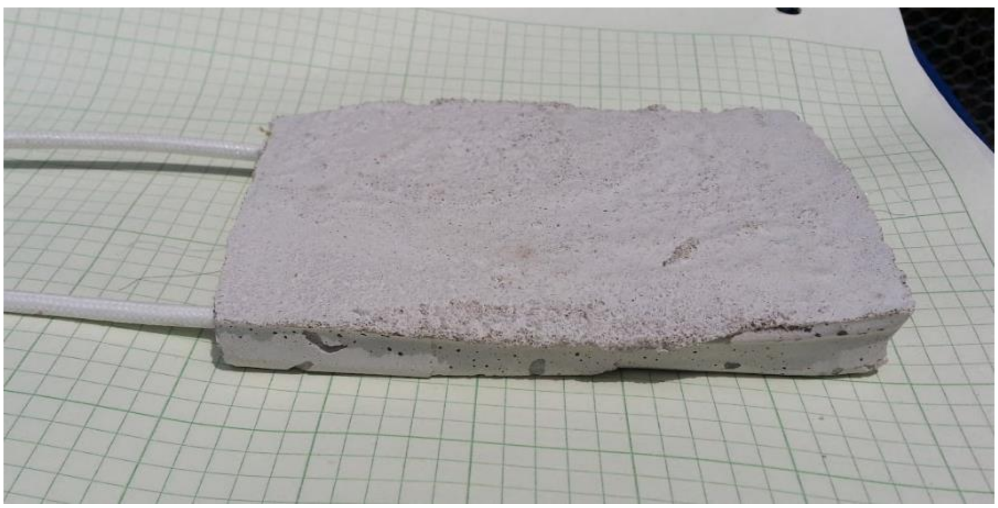


Figure 27. Completed cement burner used for the heating element for the photovoltaic cooker.

Our prototype ended up being a good model for testing our actual design. The main goal of our prototype was to match the crucial insulation requirements of our design; namely having the correct amount of insulation and having no thermal bridges leading to the outside. We avoided thermal bridging by literally floating our inner oven inside a blanket of insulation and securing the oven shut using the clasps on the outer box. Insulation was a little trickier due to the fact that our Microtherm was misplaced. We matched our design insulation as best as possible by adding the fiberglass insulation, but our prototype ended up with slightly less resistivity than our design. This difference was not large enough to disrupt any accurate testing however.

Control System

To control the temperature of our oven we decided to use an Elegoo microcontroller, a type K thermocouple, and a DC power relay. All of these components were inexpensive and simple to code. Figure 28 shows the circuit layout that we used. The thermocouple is the backbone of our temperature control. We coded the Elegoo to read the temperature off the thermocouples every 10 seconds. We were then able to command the Elegoo to control the power relay based off this temperature. The oven user inserts an oven bake temperature (desired temperature) into the Elegoo. The Elegoo receives the oven's current temperature from the thermocouple, compares it to the desired temperature, and makes a simple decision. If the current oven temperature is lower than the desired temperature the Elegoo closes the relay which allows power from the solar panel to flow to our heat source, thus increasing the oven temperature. If the current temperature is higher than desired the relay is opened and power to the burner is cut off. This results in a fluctuating oven temperature of about one degree about the desired oven temperature, which is fine for our purposes. We have included the Elegoo code we used in Appendix M. Picture of the components of the electrical circuit can be seen in Appendix O.

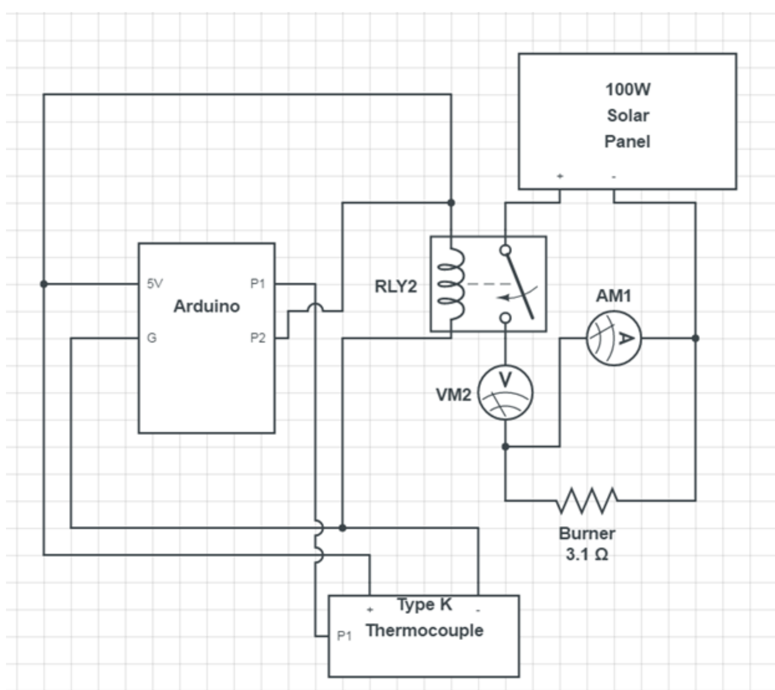


Figure 28. Portrays the electrical circuit used to control the photovoltaic prototype including the microcontroller (Arduino).

Figure 29. Our final prototype in the luscious land of the Student Experimental Farm located in San Luis Obispo. Right to Left: Pablo Arroyo and Sam “The Magnificent” Beasley

Testing

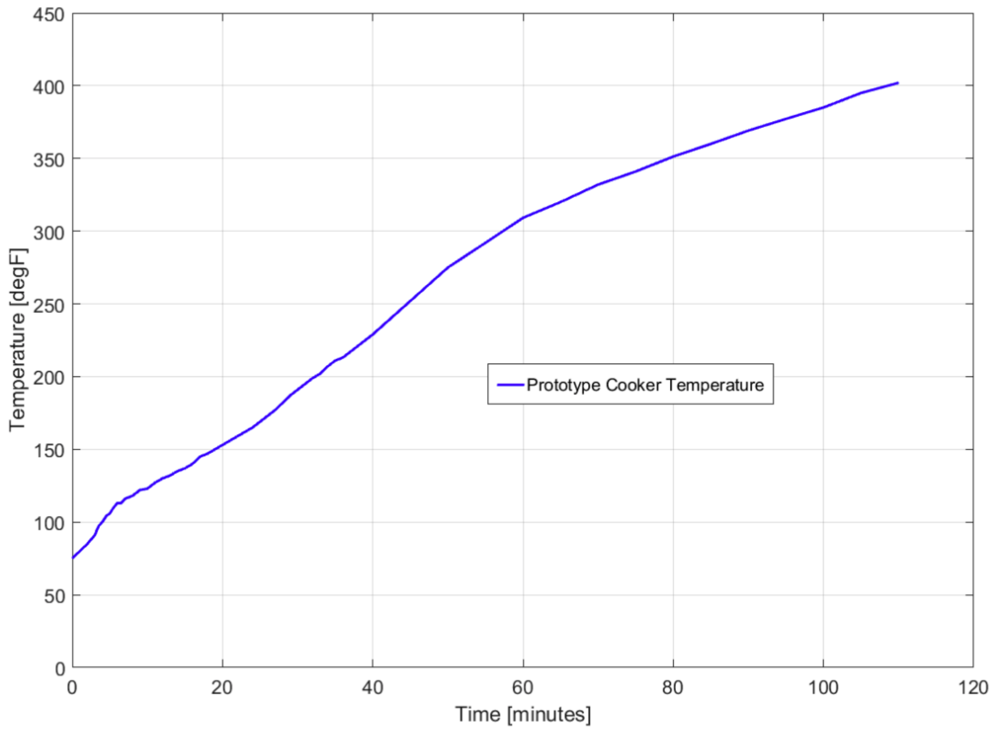


Figure 30. Time it takes to preheat our oven to 400 degrees Fahrenheit without any food inside.

For our first test, we wanted to see how fast our oven could reach 400 degrees Fahrenheit without any food or thermal mass inside. We used a power supply for our tests in order to keep the wattage constant throughout the heating process. We ended up supplying the oven with 93 watts of power to simulate a non-ideal day for our 100 watt solar panel (i.e. it is a partly sunny day and pesky clouds occasionally get in the way). It can be seen, in Figure 30, that our oven reached 400 degrees in 110 minutes, or just under two hours. We were pleased with these results, as 400 degrees is at the upper limit of temperatures we were considering cooking at. If necessary, however, our oven could handle hotter temperatures as the slope of the graph is not flattening as we approach 400 degrees.

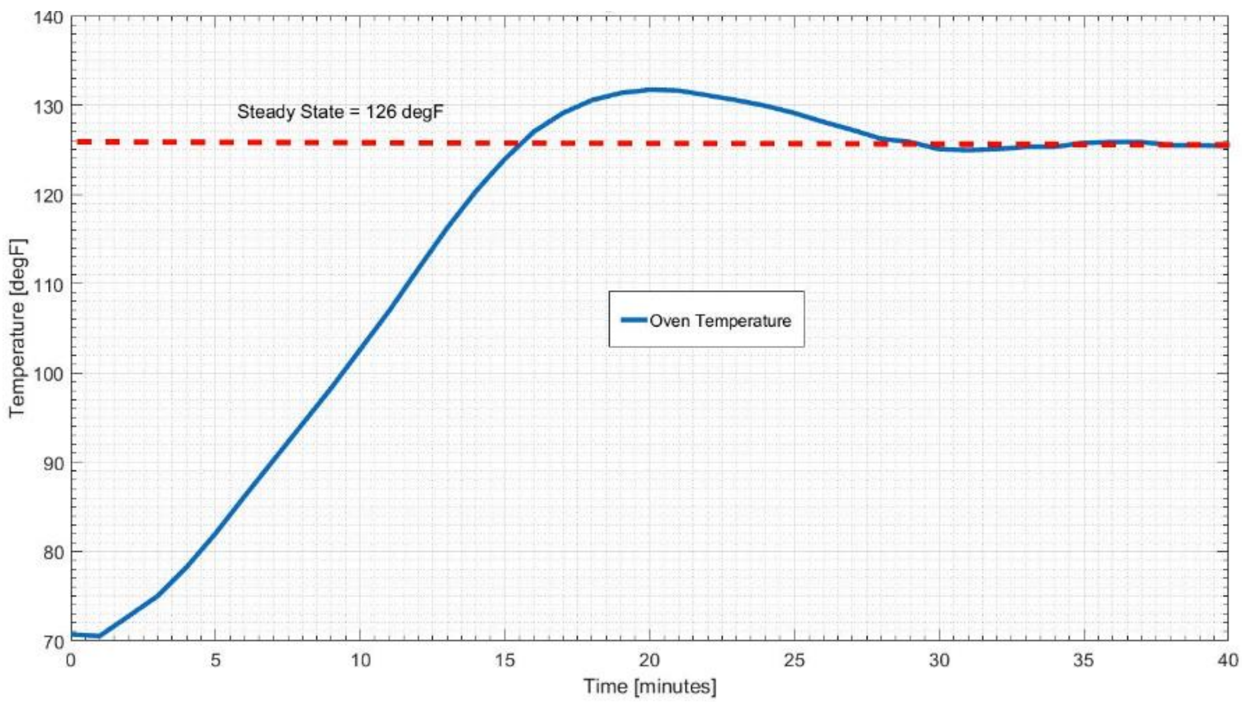


Figure 31. This plot showcases our Arduino code controlling the temperature of the oven at a preset temperature of 125 degrees.

An important part of our project was making sure we could control the temperature. It would be a poor excuse for an oven if it didn't stay at a set temperature. To see how our Elegoo code performed we set the bake temperature to 125 degrees Fahrenheit and monitored the temperature. It can be seen from the graph that after some overshoot the Elegoo steadies out the temperature nicely. The reason we chose 125 degrees is due to the fact that the oven changes temperature much easier at lower temperatures. This is why the overshoot is significant. The higher the bake temperature, however, the less the overshoot will be. We estimate that at temperatures above 250 degrees there will be virtually no overshoot at all. Even with the overshoot at these lower temperatures, the Elegoo does its job of steadying the temperature nicely at the bake temperature.

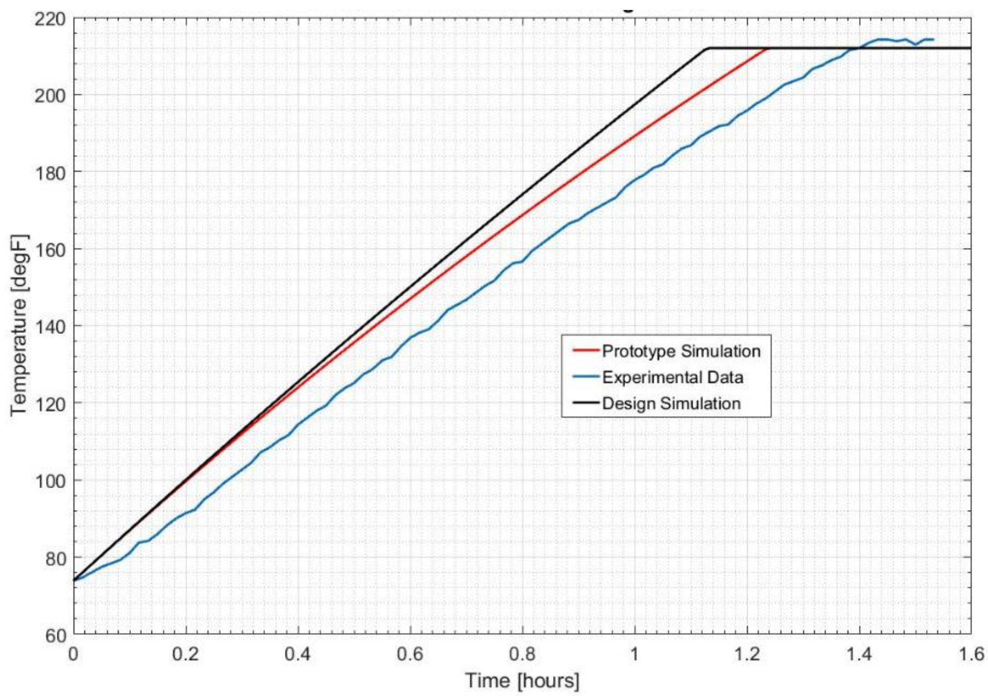


Figure 32. Displays the transient heat transfer model of our design simulation and prototype simulation compared to the experimental data

As seen in Figure 32, the prototype simulation took approximately 1.2 hours and 1.4 hours for the experiment. However, it is important to take note that our design simulation is 15% more efficient compared to our prototype simulation, which is what we assumed and hoped for. There was a 14% maximum error of the prototype simulation compared to the design simulation. This is because some of the limits of our calculation, which the main reasons are that the calculations did not take into consideration of the heat loss due to water vapor, heat loss through air convection, and heat storage from other material (aluminum walls, pot, insulation, etc.). However for our purposes, this was a great estimate for the amount of time needed to boil one liter of water. To deduce for our final design, our cooker will take between 1.05 hours to 1.2 hours to boil one liter of water.

Conclusion

This project showcased the viability of using photovoltaic cells as a sustainable source of power for camping stoves. With the price of photovoltaics trending towards zero and the interest in green practices increasing, more and more people will be looking towards solar for power. Our goal was to capitalize on this solar movement by creating a useful photovoltaic camping oven for consumers everywhere.

Our final design was made to be easy to operate, safe, and green. The main problem we had to overcome was the low power supplied by solar panels (100 Watts in our case). We had to trap as much heat in our oven as possible, and we did this by using excellent insulation and by eliminating any thermal bridging from the inner oven to the outside. The drawer feature of our oven makes it easy for the user to access food, and prevents them from having to reach into the dangerously hot inner oven. Our oven is also sturdy enough to be thrown in the back of a car and have heavy items piled on top.

Our prototype was built to ensure that the performance of our oven matched our theoretical calculations. To mimic our actual design as best as possible, we built our prototype with no areas of thermal bridging and matched the insulation to that of our design. Our testing verified our calculations quite nicely. With only 93 watts of power we were able to heat our oven to 400 degrees in under 2 hours and boil a liter of water in 1.4 hours. Our actual design is slightly better insulated than our prototype, so those numbers will improve.

Figure 33. Our final presentation at the Fall Senior Expo in Bonderson. Right to Left: Sam Beasley, Jeff Reeves and Pablo Arroyo

Overall, this project was a success. We developed several iterative tools on Matlab and Excel that can be used in the future by others for multiple heat transfer scenarios. We designed a solar powered camping oven that would be marketable to a large customer base. And we built and tested a prototype of our design which verified our calculations and proved the effectiveness of solar power. We hope that this report will be used to help aid or inspire more research and development in the field of solar energy.

References

1) *"Energy Is Essential." BioLite. BioLite, 2016. Web. 16 Feb. 2016. <http://www.biolitestove.com/pages/mission>.*
2) *"Genesis Base Camp System." JetBoil. Johnson Outdoors, 2016. Web. 16 Feb. 2016. <http://www.jetboil.com/Genesis-Base-Camp-System/>.*
3) *"GoSun Mini Kit." GoSun Stove. 2016. Web. 17 Feb. 2016. <http://www.gosunstove.com/products/gosun-mini>.*
4) The QFD template was provided by Professor Rossman from Cal Poly State University
5) "How to Make a Gantt Chart in Excel." *Gantt Chart Excel: Step-by-step, Visual Tutorial*. Web. 02 Feb. 2016.
6) "BioLite Stove - Enpundit." *Enpundit*. N.p., 06 Nov. 2012. Web. 17 Feb. 2016.
7) "Compact & Portable Cooking Systems | Jetboil." *Compact & Portable Cooking Systems | Jetboil*. N.p., n.d. Web. 17 Feb. 2016.
8) "GoSun Solar Stove." *DudeIWantThat.com*. N.p., 08 Feb. 2015. Web. 17 Feb. 2016.
9) "Microtherm®, the Most Versatile Thermal Temperature Insulation at All Temperatures." *Microtherm Nv*. N.p., n.d. Web. 03 May 2016.
10) "Make Your Own Temperature Controller with an Arduino." *MakeUseOf*. N.p., n.d. Web. 03 May 2016.
11) "Modern House Plans by Gregory La Vardera Architect: What You Don't Know about Mineral Wool Will Make You Look Stupid." *Modern House Plans by Gregory La Vardera Architect: What You Don't Know about Mineral Wool Will Make You Look Stupid.* N.p., n.d. Web. 03 May 2016.
12) "Tetron S and Virgin Unfilled PTFE." *Dotmar*. N.p., n.d. Web. 03 May 2016.
13) "6061 Aluminum Square." *MetalsDepot®*. N.p., n.d. Web. 03 May 2016.
14) "Overviews." *Sheet Metal Gauge Size Chart*. N.p., n.d. Web. 03 May 2016.
15) "High Temperature Solid Silicone Sheet." *Solid Silicone High Temperature 600F*. N.p., n.d. Web. 03 May 2016.
16) "Free 2D & 3D CAD Files, Models and Drawings of Mechanical, Electrical & Mechatronics Part Catalogs." *Traceparts*. N.p., n.d. Web. 03 May 2016.
17) "TheToggleClampStore.com." *Toggle Clamps, Latch Type Toggle Clamps, 431*. N.p., n.d. Web. 03 May 2016.

18) "Metals Depot® Shopping Cart." *Metals Depot® Shopping Cart*. N.p., n.d. Web. 03 May 2016.

19) Incropera, Frank P. *Introduction to Heat Transfer*. Hoboken, NJ: Wiley, 2011. Print.

20) Fox, Robert W., Alan T. McDonald, Philip J. Pritchard, and John C. Leylegian. *Fluid Mechanics*. Hoboken, NJ: John Wiley, 2012. Print.

Appendices:

Appendix A- QFD

Appendix B- Visual of Biolite, JetBoil, and GoSun Solar Cooker

Appendix C- Decision Matrices

Appendix D- Concept Sketches and Brainstorming

Appendix F- Preliminary SolidWorks Model

Appendix G- Management Plan

Appendix H- First concept design of the backpacking Thermos Cooker

Appendix I- DFMEA (Design Failure Modes and Effect Analysis)

Appendix J- Quotes

Appendix K- Material Properties and Data Sheets of Purchases Items

Appendix L- Construction of Final Design

Appendix M- Cost Analysis

Appendix N- Arduino Code

Appendix O- Microcontroller and Component

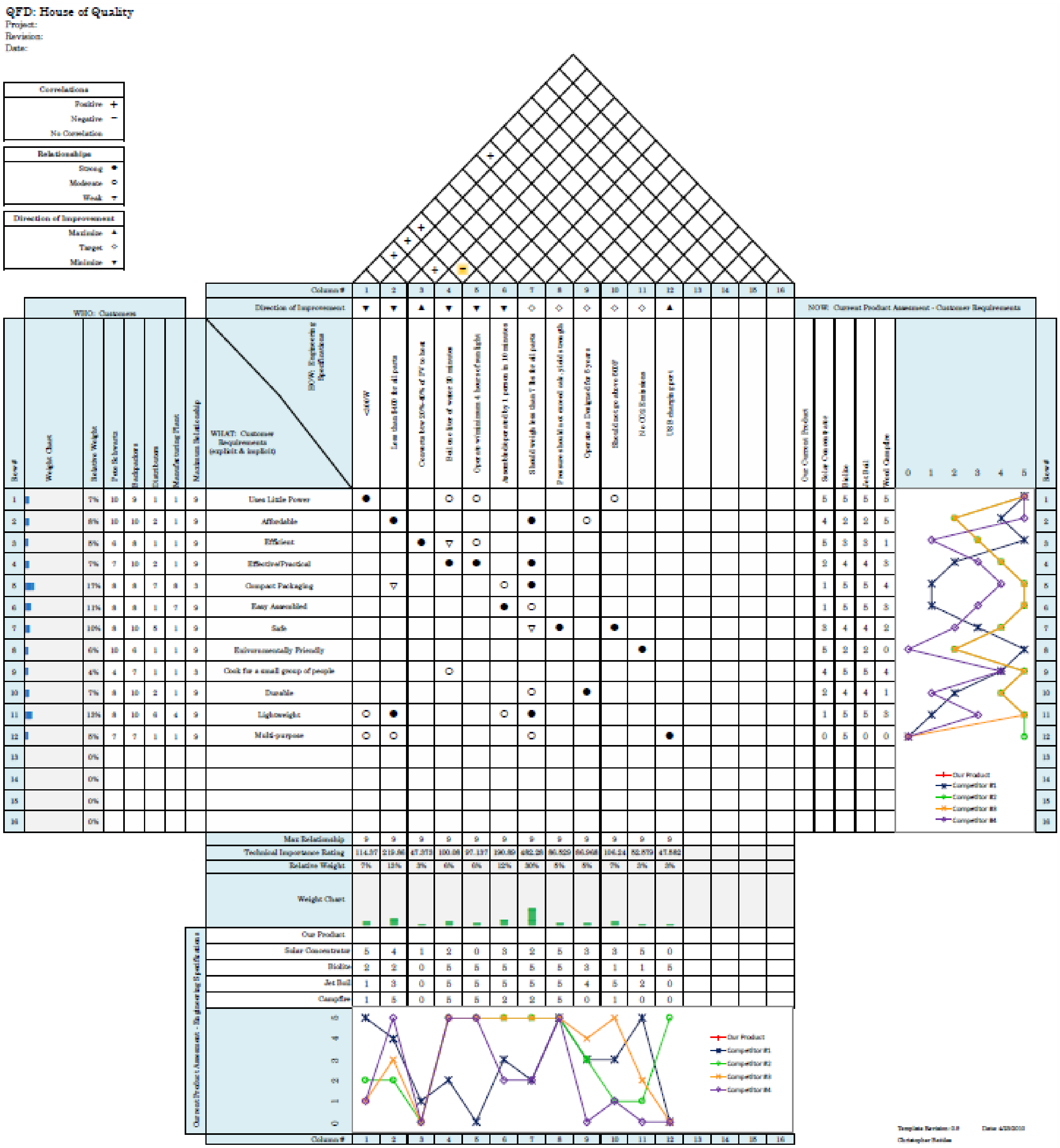
Appendix P- Engineering Equation Solver Code

Appendix Q- Transient Heat Transfer Matlab Code

Appendix R- SolidWorks Drawings

Appendix A: QFD

Note: A soft copy of the QFD will be provided as an excel file.



Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Direction of Improvement	▼	▼	▲	▼	▼	▼	◇	◇	◇	◇	◇	▲				
HOW: Engineering Specifications	<300W	Less than $400 for all parts	Converts low 20%-40% of PV to heat	Boil one liter of water 20 minutes	Operate with minimum 4 hours of sunlight	Assemblable/operated by 1 person in 10 minutes	Should weigh less than 7 lbs for all parts	Pressure should not exceed safe yield strength	Operate as Designed for 5 years	Should not go above 500F	No CO2 Emissions	USB charging port				

Row #	Relative Weight	Pete Schwartz	Backpackers	Distributors	Manufacturing Plant	Maximum Relationship	WHAT: Customer Requirements	1	2	3	4	5	6	7	8	9	10	11	12	Our Current Product	Solar Concentrator	Biolite	Jet Boil	Wood Campfire
1	7%	10	9	1	1	9	Uses Little Power	●			○	○					○				5	5	5	5
2	8%	10	10	2	1	9	Affordable		●					●		○					4	2	2	5
3	5%	4	8	1	1	9	Efficient			●	▽	○									5	3	3	1
4	7%	7	10	2	1	9	Effective/Practical				●	●		●							2	4	4	3
5	17%	8	8	7	8	3	Compact Packaging		▽				○	●							1	5	5	4
6	11%	8	8	1	7	9	Easy Assembled						●	○							1	5	5	3
7	10%	8	10	5	1	9	Safe							▽	●		●				3	4	4	2
8	6%	10	6	1	1	9	Environmentally Friendly											●			5	2	2	0
9	4%	4	7	1	1	3	Cook for a small group of people				○										4	5	5	4
10	7%	8	10	2	1	9	Durable							○		●					2	4	4	1
11	13%	8	10	6	4	9	Lightweight	○	●				○	●							1	5	5	3
12	5%	7	7	1	1	9	Multi-purpose	○	○					○					●		0	5	0	0
13	0%																							
14	0%																							
15	0%																							
16	0%																							

Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Max Relationship	9	9	9	9	9	9	9	9	9	9	9	9				
Technical Importance Rating	114.37	219.86	47.373	100.08	97.137	190.89	482.28	86.529	86.968	106.24	52.879	47.882				
Relative Weight	7%	13%	3%	6%	6%	12%	30%	5%	5%	7%	3%	3%				
Our Product																
Solar Concentrator	5	4	1	2	0	3	2	5	3	3	5	0				
Biolite	2	2	0	5	5	5	5	5	3	1	1	5				
Jet Boil	1	3	0	5	5	5	5	5	4	5	2	0				
Campfire	1	5	0	5	5	2	2	5	0	1	0	0				

Appendix B: Visual of BioLite, JetBoil, and GoSun Solar Cooker

Figure B.1. BioLite cook stove

Figure B.2. JetBoil cook stove

Figure B.3. GoSun Solar Oven

Appendix C: Decision matrices

Table C.1. Decision matrix on how to heat the cooker.

Weighted Decision Matrix -

Date last saved: Feb-23 2016

Decision Factors		Hot Plate	Spiral around Cooker	Grill-Style (Cook Directly on Heat Source)	Heat Coil Around Cooker	Heat Coils on Bottom	Heat Coils on Top	Microwaves	Phase Change
Criteria	Wt.	1	2	3	4	5	6	7	8
Power Consumption	5.0	0	3	3	4	2	2	-1	2
Production Cost	3.0	0	-1	-2	0	0	0	-1	-1
Efficienct/Practical	4.0	0	-2	-1	-3	-2	-4	5	-2
Compact Packaging	5.0	0	1	3	3	3	2	-1	1
Easy Assembled	2.0	0	-1	-1	-1	-1	-1	0	-1
Safe	3.0	0	2	1	3	3	2	0	2
Cook For Small Group	2.0	0	0	0	0	0	0	0	0
Durable	4.0	0	0	0	0	0	0	0	0
Lightweight	5.0	0	1	1	1	1	1	-1	1
Multi-purpose	2.0	0	1	3	1	2	1	3	1
Weighted Scores		0.0	20.0	32.0	**37.0**	33.0	15.0	8.0	15.0

How to heat it?	
Criteria	Definition
Power Consumption	Use less than 200W
Production Cost	Total cost will be under $400
Efficienct/Practical	Boil 1 Liter was water in less than 30 mins
Compact Packaging	Volume of 1.5 liters
Easy Assembled	Assembled/operated by 1 person in 10 mins
Safe	Outer Surface should not reach 85 degree fahrenheit
Cook For Small Group	cook for 2 peeps
Durable	last for 5 years
Lightweight	less than 7lbs for all parts
Multi-purpose	usb- charge electronics, grill, boil, pressure cooking, various cooking styles

Note on calculation
The formula for weighted scores uses a Sumproduct formula and has conditional formatting applied. Please check that the formula and conditional formatting includes the correct cell ranges if you add or remove any rows or columns.

Instructions: Select and insert a score of **-5 to +5** for each criteria. The score will be multiplied by the weight to arrive at the total weighted score.
Keep the first column for **status quo** (i.e. no change) and score the options against the status quo.

Table C.2. Decision matrix for insulation

Weighted Decision Matrix -

Date last saved: Feb-25 2016

Decision Factors		Fiberglass Oven Insulation	Vacuum	Sawdust	Rubber Foam	Polyurethane Foam	Polystyrene Foam	MicroTherm	Ceramic Fiber Blanket	Wool	REI Megamat (polyurethane)	Air	AeroGel
Criteria	**Wt.**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Conductivity	5.0	0	5	3	1	4	3	4	2	4	4	4	5
Density	3.0	0	5	3	-2	3	4	-4	-4	-3	4	5	4
Cost	3.0	0	-3	5	-1	2	3	-3	-2	4	-3	-1	-4
Flammable	5.0	0	0	-1	0	0	0	0	0	-1	0	0	-1
Temperature Resistant	4.0	0	5	-1	-4	-4	-5	5	5	4	-3	5	3
Safe (Toxic)	3.0	0	1	1	1	1	-1	1	0	1	1	1	-1
Natural	2.0	0	1	1	0	0	0	0	0	1	0	1	0
Durable	4.0	0	3	-2	2	2	-1	3	4	4	2	2	2
Malleable	4.0	0	-3	4	2	4	-1	2	2	4	3	4	-4
Weighted Scores		0.0	56.0	43.0	-1.0	46.0	5.0	42.0	36.0	71.0	34.0	**81.0**	21.0

Insulation?	
Criteria	**Definition**
Conductivity	low as possible
Density	low as possible
Cost	low as possible
Flammable	no
Temperature Resistant	anything above 500 degree F
Safe (Toxic)	no
Natural	environmentally friendly to produce and recycleable
Durable	last for 5 years
Malleable	can fit contours

Note on calculation
The formula for weighted scores uses a Sumproduct formula and has conditional formatting applied. Please check that the formula and conditional formatting includes the correct cell ranges if you add or remove any rows or columns.

Instructions: Select and insert a score of **-5 to +5** for each criteria. The score will be multiplied by the weight to arrive at the total weighted score.
Keep the first column for **status quo** (i.e. no change) and score the options against the status quo.

Table C.3. Decision matrix for portability

Weighted Decision Matrix -

Decision Factors		Propane Cook Stove with pot	Compressible stove that goes on backpack	Standard Rectangle For Car Camping	Built into Chair	Thermos Sized cooker	"Pop up tent" Cooker	Clippable modular synergetic solar de	Drawer Cooker
Criteria	Wt.	1	2	3	4	5	6	7	9
Quantity of Food	2.0	0	1	4	4	0	3	4	4
Power Efficient	4.0	0	2	4	4	4	3	2	4
Applicable	5.0	0	4	4	4	4	4	4	4
Compact Packaging	5.0	0	-1	-5	-4	1	1	1	-1
Easy Assembled	3.0	0	2	4	-1	3	-1	-3	-1
Safe	4.0	0	2	4	2	4	1	1	2
Durable	2.0	0	3	4	3	4	-1	2	3
Lightweight	4.0	0	0	-4	-4	3	5	3	-3
Multi-purpose	5.0	0	3	4	5	2	3	2	4
	3.0	0							
Weighted Scores		0.0	60.0	59.0	44.0	**96.0**	77.0	62.0	58.0

Portability of Camping Oven	
Criteria	Definition
Quantity of Food	More the merrier
Power Efficient	Insulationability (will it be easy to add insulation for better efficiency)
Applicable	Does the design have a place in the target market
Compact Packaging	Does not take up too much room
Easy Assembled	Takes less than 5 minutes to assemble
Safe	Explosive? Pinch points? Radioactive?
Durable	Reliability works for 5 years
Lightweight	Lighter the better
Multi-purpose	Can you cook different ways? Add a USB power port? Use at home?
0	NOTE !!!!! Food quantity to cooker size ratio is important. Try to make cooker size match portions

Note on calculation
The formula for weighted scores uses a Sumproduct formula and has conditional formatting applied. Please check that the formula and conditional formatting includes the correct cell ranges if you add or remove any rows or columns.

Instructions: Select and insert a score of **-5 to +5** for each criteria. The score will be multiplied by the weight to arrive at the total weighted score.
Keep the first column for **status quo** (i.e. no change) and score the options against the status quo.

Table C.4. Decision matrix for temperature control

Weighted Decision Matrix -

Decision Factors		[illegible]	[illegible]	Cooling fan	[illegible]	Arduino temp sensor	[illegible]				Controlling Temperature	
Criteria	Wt.	1	2	3	4	5	6	7	8	9	Criteria	Definition
Compact	5.0	0	1	-1	5	1	1				Compact	Does it fit inside/integrate with the apparatus?
Power Efficient	4.0	0	4	-3	5	2	2				Power Efficient	Does is use power to run the controlling system
Durable	2.0	0	2	1	5	4	3				Durable	Reliability works for 5 years
Affordable	2.0	0	-3	-1	5	3	2				Affordable	As little $$$ as possible
Lightweight	3.0	0	0	-1	5	0	0				Lightweight	Lighter the better
Safe	4.0	0	1	1	-2	1	1				Safe	Harmful chemicals? Explosive?
											0	
											0	
											0	
Weighted Scores		0.0	23.0	-16.0	72.0	31.0	27.0	0.0		0.0		

Note on calculation
The formula for weighted scores uses a Sumproduct formula and has conditional formatting applied. Please check that the formula and conditional formatting includes the correct cell ranges if you add or remove any rows or columns

Instructions: Select and insert a score of -5 to +5 for each criteria. The score will be multiplied by the weight to arrive at the total weighted score.
Keep the first column for status quo (i.e. no change) and score the options against the status quo.

Table C.5. Decision matrix for controlling temperature

Weighted Decision Matrix -

Decision Factors		[illegible]	[illegible]	Cooling fan	[illegible]	[illegible]	[illegible]			
Criteria	Wt.	1	2	3	4	5	6	7	8	9
Compact	5.0	0	1	-1	5	1	1			
Power Efficient	4.0	0	4	-3	5	2	2			
Durable	2.0	0	2	1	5	4	3			
Affordable	2.0	0	-3	-1	5	3	2			
Lightweight	3.0	0	0	-1	5	0	0			
Safe	4.0	0	1	1	-2	1	1			
Weighted Scores		0.0	23.0	-16.0	72.0	31.0	27.0	0.0		0.0

Controlling Temperature	
Criteria	Definition
Compact	Does it fit inside/integrate with the apparatus?
Power Efficient	Does is use power to run the controlling system
Durable	Reliability works for 5 years
Affordable	As little $$$ as possible
Lightweight	Lighter the better
Safe	Harmful chemicals? Explosive?
0	
0	
0	

Note on calculation
The formula for weighted scores uses a Sumproduct formula and has conditional formatting applied. Please check that the formula and conditional formatting includes the correct cell ranges if you add or remove any rows or columns.

Instructions: Select and insert a score of -5 to +5 for each criteria. The score will be multiplied by the weight to arrive at the total weighted score.
Keep the first column for status quo (i.e. no change) and score the options against the status quo.

Table C.6. Decision matrix for drawer latch selection

Weighted Decision Matrix -

Decision Factors		Handle	Cam Action Latch	Mechanical Oven Latch	Magnetic Latch	Spring				
Criteria	Wt.	1	2	3	4	5	6	7	8	9
Compact	5.0	0	-1	-3	-2	5				
Safe	5.0	0	2	2	1	-4				
Durable	2.0	0	0	0	-1	-2				
Affordable	2.0	0	-1	-1	-1	-1				
Lightweight	2.0	0	-1	-1	-1	1				
Mounting	4.0	0	0	0	0	-3				
Tight Seal	5.0	0	3	3	2	1				
Weighted Scores		0.0	16.0	6.0	-1.0	-6.0	0.0	0.0		0.0

Drawer Latch	
Criteria	Definition
Compact	Smaller the better
Safe	Resistant to high heat? Won't burn the user
Durable	Reliability works for 5 years
Affordable	As little $$$ as possible
Lightweight	Lighter the better
Mounting	As little steps as possible
Tight Seal	As tight as possible

Note on calculation
The formula for weighted scores uses a Sumproduct formula and has conditional formatting applied. Please check that the formula and conditional formatting includes the correct cell ranges if you add or remove any rows or columns.

Appendix D: Concept sketches and brainstorming

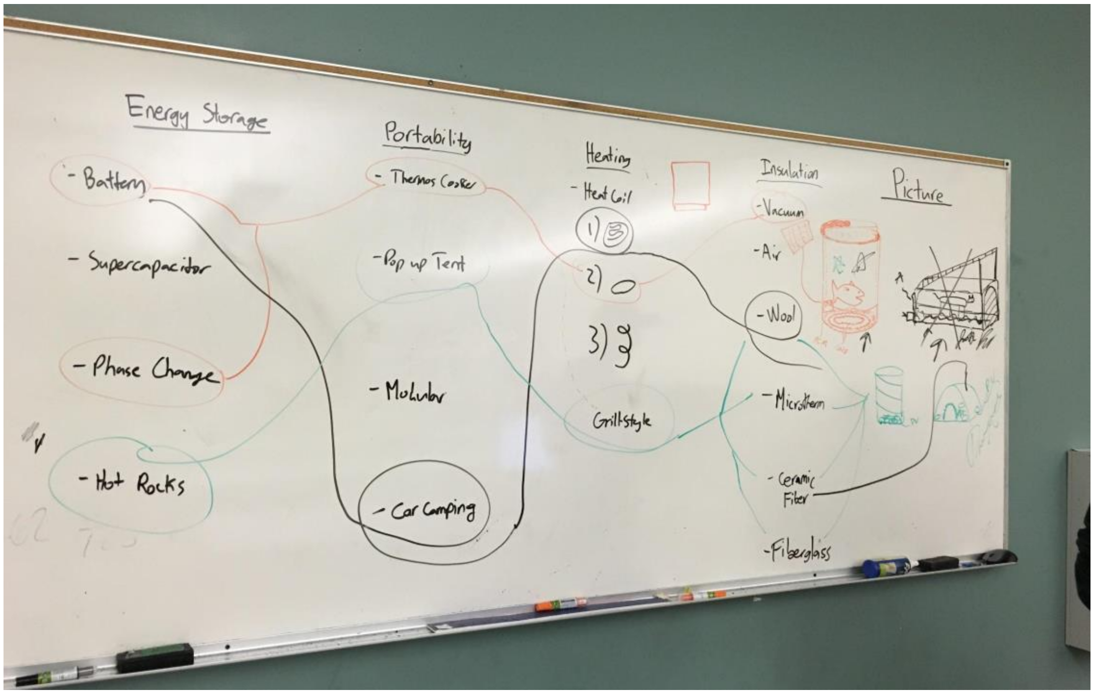


Figure D.1. Concept design brainstorming

This was a brainstorming technique done by selecting four different categories for. In each category, techniques used to satisfy the criteria were written done. Afterwards, each group member chose a technique from each of the categories which together create a rough concept design. Then each of the group member drew a sketch of their interpretation of the concept.

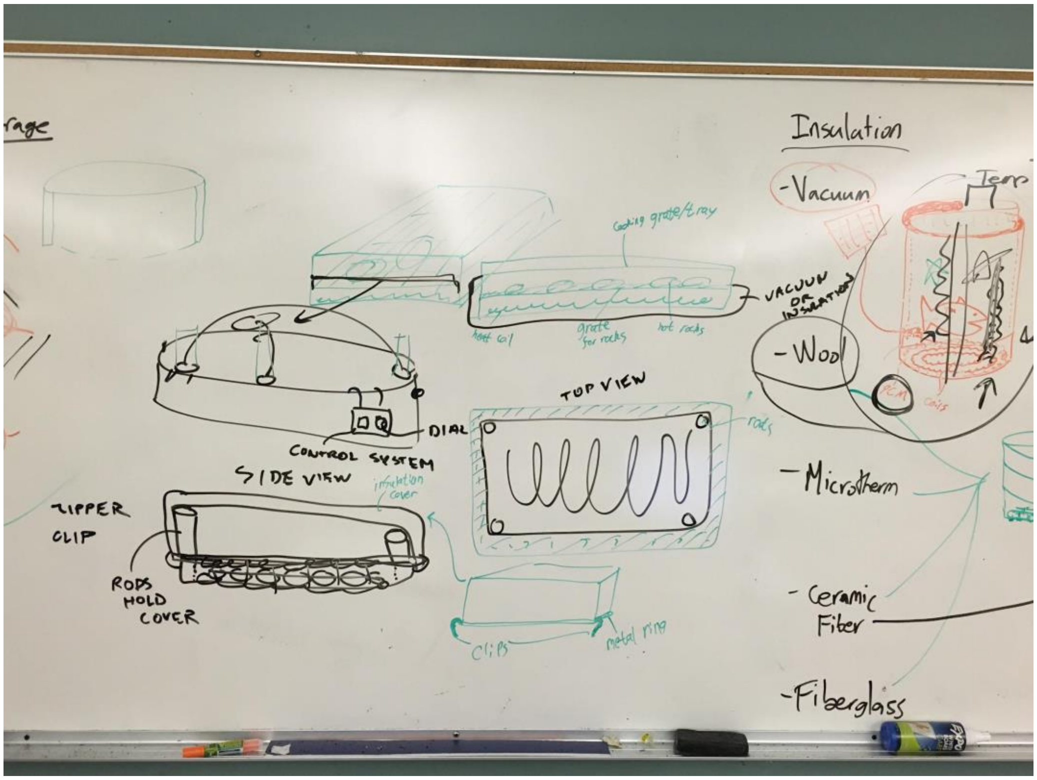


Figure D.2. Concept sketch of the car camping cooker

The concept of making a car camping cooker was chosen. In this picture, two concepts were made, and each group member took turn in modifying the concept. In this picture, the first concept was making it rectangular and rods were used to hold the cover in place. Metal clips were used to hold the cover down in place. The second concept was an iteration of the first making make it circular instead of rectangular.

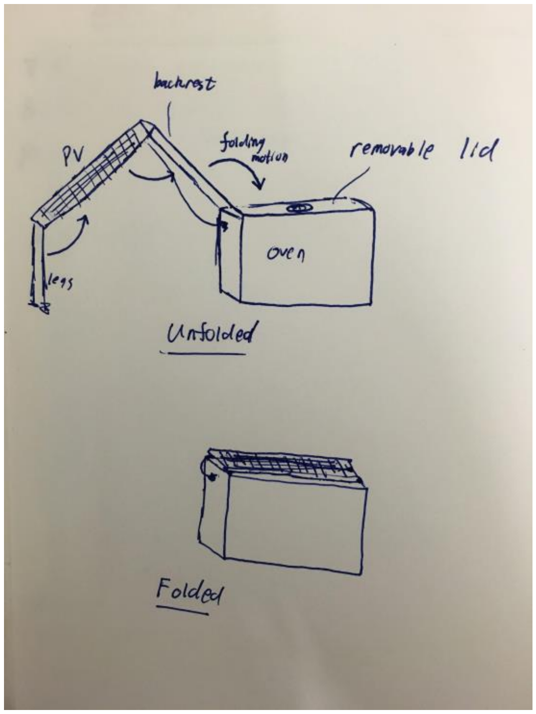


Figure D.3. Concept sketch of the fold-up chair cooker

This concept was discovered by one of the group members during our brainstorming session. The basic concept was making the cooker foldable chair. The purpose of this chair was that the solar panel would fold out and serve as a backrest. The person can then sit on the chair which provides four services: keeping the lid close, insulating the oven, providing a suitable place for someone to sit and it can be used as a sit warmer.

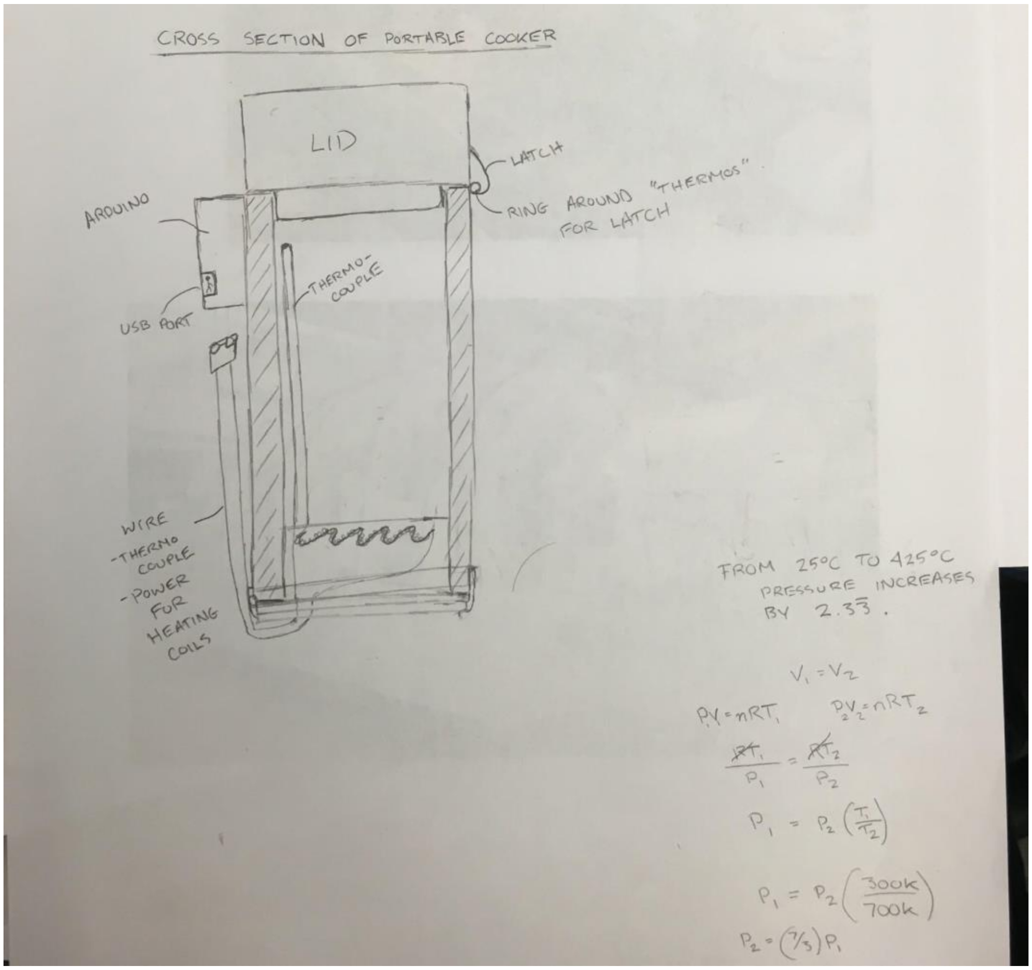


Figure D.4. Concept sketch of the thermos cooker

This was a concept design for backpacking. It involved taking a thermos and transforming it to a cooker. It was a two piece cooker: the bottom contains the heating element which can be removed for cleaning purposes and the top was the lid in which the user can insert their food. Attached to the side of the thermos cooker was the temperature control system used for inputting the desired temperature and controlling the inside temperature of the cooker. Also, a battery would be used to aid the solar panel it providing the necessary power to cook the food. It would be small and compact so that anybody can take it backpacking and enjoy a nice meal without the use of a fire.

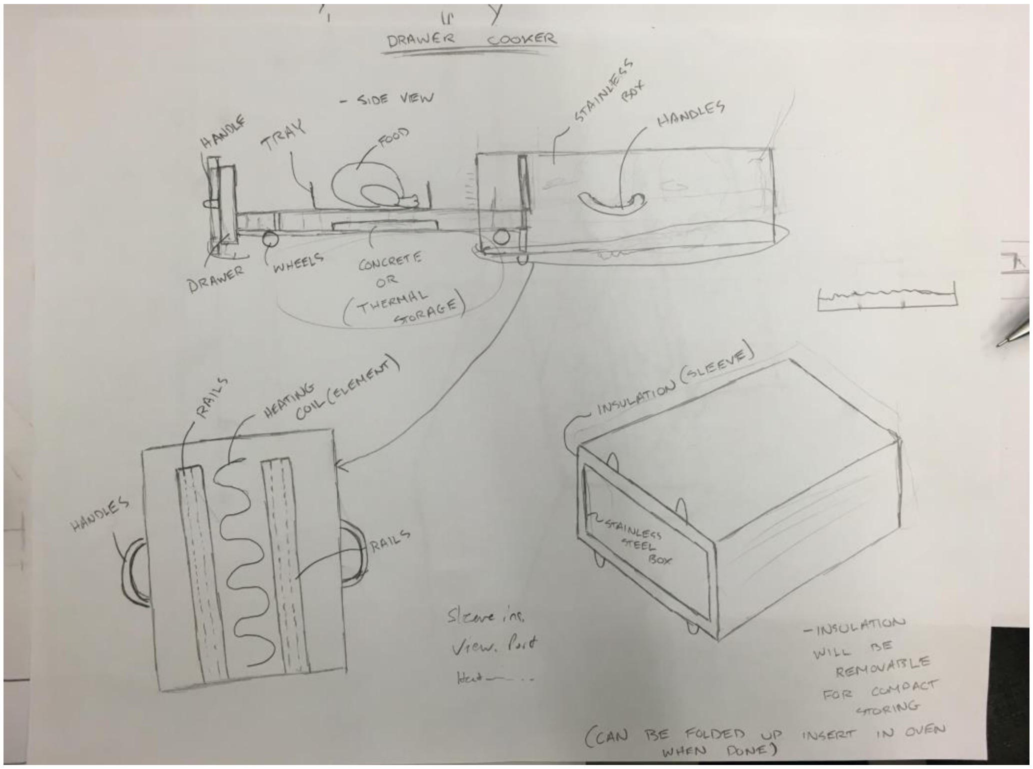


Figure D.5. Concept sketch of the drawer cooker

This was a rough sketch of the beginning of our final concept. This concept is thoroughly explained in the body of the report.

Appendix F: Preliminary SolidWorks models

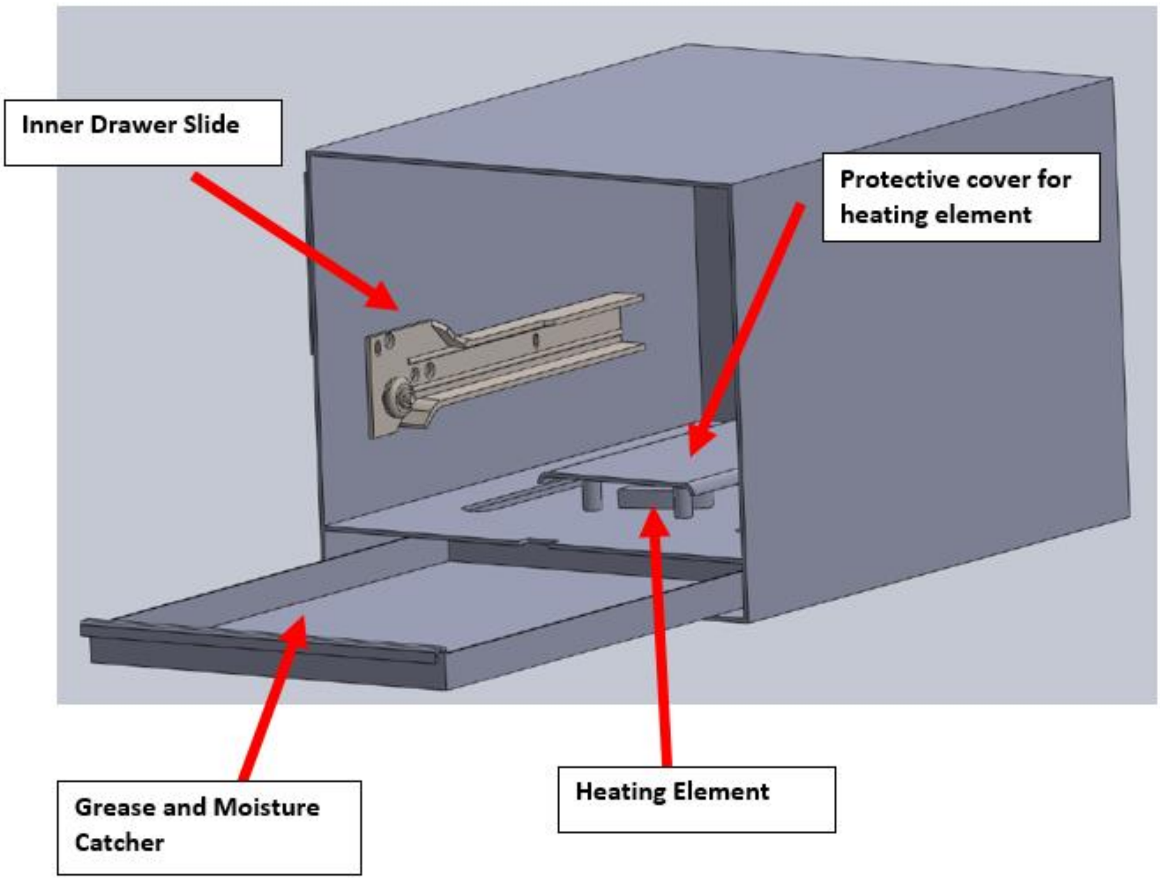


Figure F.1. Solid model of the open cooker

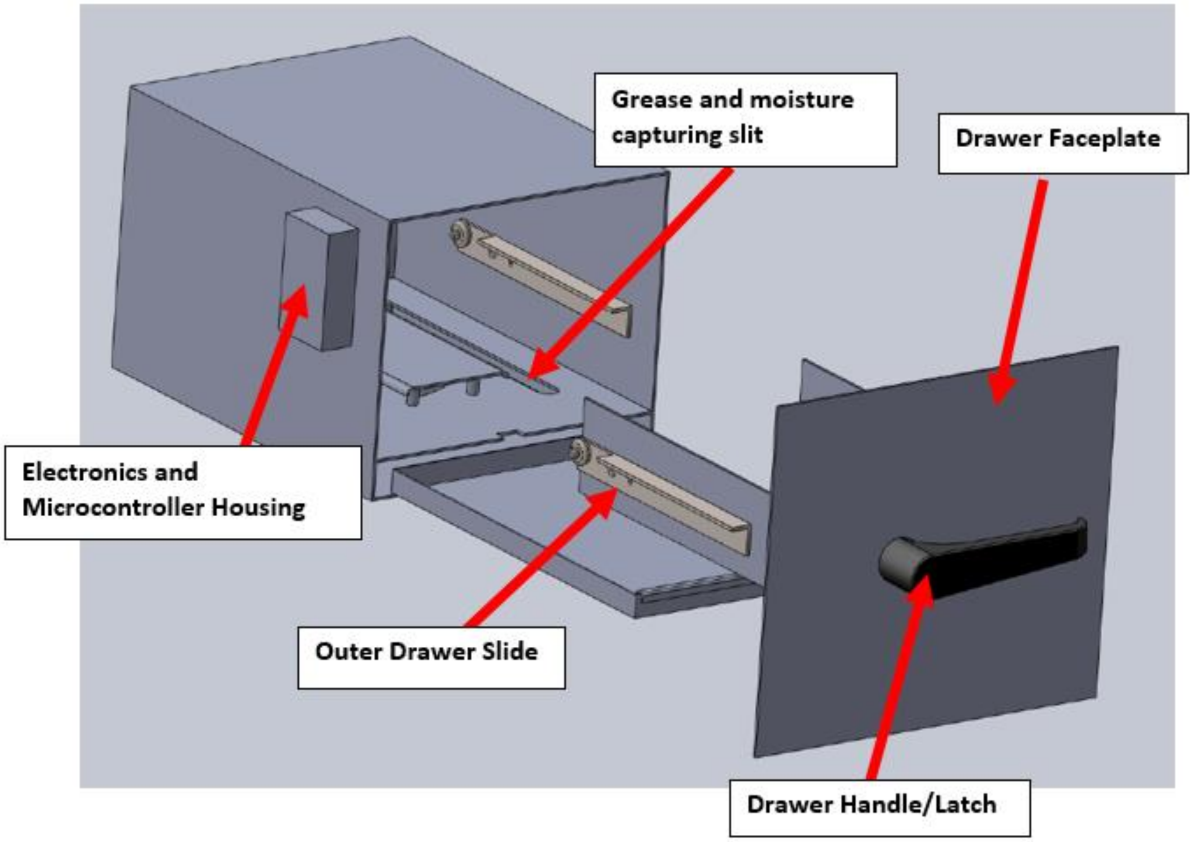


Figure F.2. Full assembly of the cooker including the “drawer”.

Appendix G: Management Plan

Our main focus for this project is to build a functioning prototype and see how well it performs. We will cycle through a simplified four cycle rotation of *design, build, test, and iterate*. A detailed schedule of the Gantt Chart is shown below in Table 3, and the Gantt Chart is shown in Figure 3. During the design phase, all of the engineering requirements will be reviewed and used as a guide. Solidworks drawings, engineering calculations, and software modeling will be created to predict our design's functionality and capability. After creating a design that theoretically meets the engineering requirements, we will build a working prototype. There will only be one iteration for the whole project, so most of the time will be analyzing the theoretical design before we create the prototype to ensure that our project will function under the specified design requirements.

We have documented our time in relationship with our tasks by using a Gantt chart[5] which displays the amount of work done in certain periods of time. Our Gantt chart can be seen Table 3 and Figure 3 below. Our main goal is to have one design iteration built and documented in a Final Design Report by the end of April. Our prototype will be presented at the spring expo, however, it will be presented as a project still in the design process. Afterwards, during the fall quarter the project will be tested and verified for functionality.

Table G.1. Detailed schedule of Gantt Chart

Task Name	Start	End	Duration (days)
Project Proposal	1/14/2016	2/2/2016	19
Project Proposal #2	2/2/2016	2/17/2016	15
Brainstorming-Concept Design	2/18/2016	2/26/2016	8
Concept Design Review	2/18/2016	2/29/2016	11
Design Analysis	2/29/2016	4/2/2016	33
Final Design Report	4/2/2016	4/26/2016	24
Building	4/26/2016	5/22/2016	26
Testing	5/22/2016	10/31/2016	162
Safety	10/1/2016	10/31/2016	30
Senior Project Expo	10/31/2016	11/14/2016	14

Appendix H: First concept design of the backpacking Thermos cooker

Our second concept is designed to be much more portable than the car camping cooker. We call this concept the Solar Thermos Cooker and it is meant for backpacking and fishing trips. The Thermos Cooker closely resembles the shape of any conventional insulated drink-holder. Inspiration for this design came from the Hydro Flask water bottles that some of us own. Most thermoses, like the Hydro Flask, are vacuum insulated due to the fact that a very thin layer has incredibly low thermal conductivity. This saves a lot of space and provides great insulation. For these reasons, we would also like our thermos to have a vacuum insulated cylindrical body. However, there are going to be a few changes between our design and a conventional thermos. Our thermos is going to be able to hold 1.5 Liters of fluid and will have a heating element attached to the inside base. Both the lid and the base of the thermos will be removable for cleaning purposes. Also, both the lid and the base will attach to the body of the thermos using latches instead of conventional threads. This allows for the thermos to be better insulated. The insulated base will include the device's heat coils and a thermocouple for temperature measurements. The wires from the thermocouple and heating element will be fed through the base and to a control housing. This control housing will be located on the side of the thermos near the very top. It will contain the arduino that controls our cooker. It will also contain a USB port and a simple temperature readout.

The temperature readout will have two basic settings, one that reads the current temperature in the cooker and one that allows the user to set a desired temperature. After a desired temperature is input, the arduino control board begins the heating process. It transfers all power from the solar panel to the heating element. After the inside of the thermos reaches the desired temperature, the arduino will transfer power from the cooker to the USB port. The user can use the power supplied to the USB port to their own liking. The arduino will continually monitor the cooker's inner temperature and redirect power back to the heating element if the temperature drops too low.

In order to hold food, we decided to use a steel grill basket much like you'd find on a standard barbeque at home depot. The grill basket will be surrounded with ⅛" steel round and the food will be "sandwiched" in between with a steel mesh. There will be two steel brackets which are

screwed to the inside of the lid. These brackets will hold the grill basket in place with a pin which is inserted through tapped holes at the end of the steel rounds. With this setup, the thermos can be in any orientation and still successfully cook the food. Once the food is cooked, the lid gets removed and pulled out with the grill basket and food still attached. To boil water or make beans, the user can pour the liquid directly into the thermos. Every component will be waterproof and non-toxic.

The lid and the bottom will be secured to the cooker with snap latches. There will be a small ring machined around the top edge of the lid and bottom edge of the cap which will allow the latches to grab and hold the two components to the body. Unlike regular water bottles and thermoses, our thermos will have the majority of our lid and base hanging inside the body of the bottle with a layer or temperature resistant insulated plastic. The nichrome heat coils will be pressed closely against a steel plate on the base and will heat the food/liquid inside the thermos via current supplied by the photovoltaic panel. Behind the steel plate will be another temperature resistant plastic for insulation. Descriptions for how the thermos cooker design meets the customer needs and engineering requirements can be found in table 15 and 16 below

Table H.1. How our design meets the customer needs for the thermos cooker

Customer Requirements	**How it meets Customer Requirement**
Affordable	Due to the small size of the cooker, materials and electronics will be relatively cheap. A smart and efficient manufacturing process for creating the vacuum insulation will be implemented to lower the price further.
Effective/Practical	This concept cooker will be relatively lightweight and easy to carry relative to other sun powered cookers on the market. This will allow the cooker to be portable, which will appeal to many consumers. Another bonus of the design is the fact that a backpack solar panel can be implemented with this design to cook food while hiking.
Can be used all year	Whenever there is sun, our cooker will be able to make delicious meals.

Easily Assembled	Everything in the design is easily clipped, screwed, or pinned into place. We estimate that assembly should take no longer than 2 minutes
Durable	The cooker will be made out of sturdy metals that are made to last. All sensitive electronics will be well shielded from heat.
Easy access to food	The food is easy to access. All that is needed is to remove either the top or bottom of the cooker and you can instantly access the contents within.
Safe	Like any cooking device, users will need to be safety conscious when making food. With this design, food is accessed by removing the bottom part of the cooker, which is opposite of the heating coil. This ensures that the user does not have to dodge the heating coils when removing food. Due to the insulation, no exterior surfaces will burn a human.

Table H.2. How our design meets the engineering requirements for the thermos cooker

Engineering Specifications	**How it meets Engineering Requirement**
Requires <250 Watt solar panel	Our design will implement a portable solar panel significantly smaller, lighter, and less powerful than the 250 Watt limit.
Costs less than $400 for all parts (including solar panel)	This design does not require any exotic materials/electronics that will spike the price. We will carefully choose materials that minimize cost while maintaining function. The largest concern is minimizing the manufacturing costs associated with the vacuum insulation.
Boil a liter of water in <30 minutes	After performing initial heat transfer calculations included in Appendix D. We theoretically estimate that this requirement will be met.
Assembled by 1 person in 10 minutes	We estimate that the entire assembly process should take less than 2 minutes.
Pressure should not exceed calculated yield strength	We will include a pressure release valve in the design to relieve any dangerous pressure buildup.
Operated by one person	This concept was designed to be easily operated by a single person.
Exterior Temperature does not exceed 110 F	The exterior temperature will remain below 110F
Minimum lifetime of 5 years	The cooker will be made out of sturdy metals that are made to last. All sensitive electronics will be well shielded from heat by long lasting insulation.
Contains USB charging port	This design includes a USB port.

Appendix I: DFMEA

Potential
Failure Mode and Effect Analysis
(Design FMEA)

___ System			FMEA Number:
___ Subsystem			
___ Component	Design Responsibility:		Page 1 of 1
Model Year(s)/Vehicle(s):	Key Date:		Prepared By:
Core Team: Jeff Reeves, Sam Beasley, Pablo Arroyo			FMEA Date (Orig.) (Rev.)

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occur	Crit	Recommended Action(s)	Responsibility & Target Completion Date	Action Results: Actions Taken	Sev	Occur	Crit
Outer surface	May get very hot	Could burn the user	9	Insulation is not adequate Oven gets much hotter than designed for	4	36	Using heat transfer analysis, numerically determine max outer wall temp.	5/21/2016				
Rails	Rails could get jammed	Make it difficult for the user to open/close	4	Grease or grime buildup Drawer slides wear out	7	28	Keep the rails well lubricated. Dimension the drawers with proper tolerances	5/3/2016				
Micro-controller	Does not properly regulate temperature	Either gets too hot and burns the food or it doesn't get hot enough	8	Poor coding Recieves inaccurate temperature information	5	40	Work closely with Omar and our sponsor to make sure the Arduino is set up properly	5/21/2016				
Inner walls and door/latch	Pressure may become too high, shooting steam or hot air into user's face while opening	Could injure the user or make it very uncomfortable to open the oven	9	No proper pressure release system in place	5	45	Use our design analysis to determine the max pressure inside the device.	5/18/2016				
Wire damage	Wires may melt or get damaged	Controls will not work	8	High heat or moisture damage	4	32	Purchase wires that are resistant for temperatures up to 500 degrees Fahrenheit	5/21/2016				
Latched door malfunctioning	Door may not close or get way too hot	Could burn the user's hand or let all the heat escape if it doesn't close	9	Dimensions for the door don't match. Heat could conduct through the latch	3	27	Dimension the latches with proper tolenances Place latch far enough away so it	5/18/2016				
Failure on user interfaces (buttons and such)	Repeated use (pressing buttons or turning dials)	User loses control over oven settings	6	Fatigue from repeated button use	5	30	Make control housing easily accessible in case LCD display needs to be replaced	5/10/2016				
Thermocouples may get dirty	May get coated with grease from food or other particulates	This could affect the accuracy of the thermocouple readings, which are	7	User may be cooking oily/greasy food. They could also coat the thermocouples with food while loading the	5	35	Keep thermocouple accessible so the user can clean it if necessary.	5/21/2016				
Nichrome Wire	May break or wear down	Heating element may become much less efficient, or fail	6	Multiple uses may change properties of wire, affecting its performance	4	24	Keep nichrome wire secured to the floor of the oven so it doesn't shake loose and get damaged	5/28/2016				
Drawer	Drawer experiences different loading scenarious	Drawer may break or sag	5	Fatigue over time Too heavy of a load	2	10	Reinforce inner body of the oven so it does not yield or buckle	5/28/2016				

Appendix J: Quotes

Promat

Quotation
Cal Poly ½" quilt
4/28/2016

Sam Beasley
Cal Poly
'Sam Beasley' <sambe44@gmail.com>

Thank you for your inquiry into Promat High Performance Insulation. We are pleased to confirm pricing and dispatch as follows:

Material:

Quantity	Description	Size	Each (US$)	Total (US$)
1			$58.00	$58.00
40pc/box	½" Microtherm 1000X quilted	1220x610x12.5mm	$46.40	$1,865.00/box
10+ boxes			$42.20	$1,688.00/box

- Lead Time: TBD
- Incoterms: Ex Works - Maryville, TN
- Freight: TBD
- Quote Validity: 90 days
- Payment Terms: TBD
- Minimum Order Required: $300.00

Thank you for this opportunity to quote. We hope to be of service in the near future.

Sincerely,

Jessee L. Black
Inside Sales Manager
PROMAT INC
North America
j.black@promat.us
jb

Figure J.1: Promat (Microtherm) 0.5" quilted panel

Appendix K: Material properties and data sheets of purchased items.

Professional Plastics

The Global Leader in High Performance Plastics

TYPICAL PROPERTIES of POLYETHYLENE

ASTM or UL test	Property	LDPE	HDPE	UHMW
PHYSICAL				
D792	Density (lb/in^3) (g/cm^3)	0.033 0.92	0.035 0.95	0.034 0.93
D570	Water Absorption, 24 hrs (%)	<0.01	0	0
MECHANICAL				
D638	Tensile Strength (psi)	1,800-2,200	4,600	3,100
D638	Tensile Modulus (psi)	-	-	125,000
D638	Tensile Elongation at Yield (%)	600	900	-
D790	Flexural Strength (psi)	-	-	-
D790	Flexural Modulus (psi)	-	200,000	125,000
D695	Compressive Strength (psi)	-	-	2,000
D695	Compressive Modulus (psi)	-	-	-
D785	Hardness, Shore D	D41-D50	D69	D62-D66
D256	IZOD Notched Impact (ft-lb/in)	No Break	3	No Break
THERMAL				
D696	Coefficient of Linear Thermal Expansion (x 10^{-5} in./in./°F)	3	6	11
D648	Heat Deflection Temp (°F / °C) at 66 psi at 264 psi	 120 / 48 105 / 36	 170 / 76 150 / 40	 203 / 95 180 / 82
D3418	Approx. Melting Temperature (°F / °C)	230 / 110	260 / 125	280 / 138
-	Max Operating Temp (°F / °C)	160 / 71	180 / 82	180 / 82
C177	Thermal Conductivity (BTU-in/ft^2-hr-°F) (x 10^{-4} cal/cm-sec-°C)	 - -	 - -	 2.92 10.06
UL94	Flammability Rating	n.r.	n.r.	H-B
ELECTRICAL				
D149	Dielectric Strength (V/mil) short time, 1/8" thick	-	-	900
D150	Dielectric Constant at 50 kHz	-	-	2.3
D150	Dissipation Factor at 50 kHz	-	-	0.0002
D257	Volume Resistivity (ohm-cm) at 50% RH	-	-	>5 x 10^{18}
D495	Arc Resistance (sec)	-	-	-

Figure K.1. Polyethylene material properties

Mineral Wool Pipe Insulation

Performance and Compliance

ASTM C612 Mineral Fiber Block and Board Thermal Insulation Type IVB.

ASTM C547 Standard Specifications for Mineral Fiber Pipe Insulation Type 1 Grade A (850°F).

ASTM C585-90 (2004) Standard Practice for Inner and Outer Diameters of Rigid Thermal Insulation for Nominal Sizes of Pipe and Tubing (NPS System).

ASTM C450 Standard Practice for Fabrication of Thermal Insulating Fitting Covers for NPS Piping, and Vessel Lagging.

Fire Performance

ASTM E 84 Surface Burning Characteristics

(UL723) Flame Spread 5, Smoke Developed 0

CAN/ULC S102 Surface Burning Characteristics
Flame Spread 5, Smoke Developed 0

ASTM E 136 Behavior of Materials at 750°C (1382°F)
Non-Combustible

CAN4 S114 Test for Non-Combustibility
Non-Combustible

Maximum Service Temperature

ASTM C 411 Hot Surface Performance
In Compliance with ASTM C612
@ 1200°F (650°C).

Moisture Resistance

ASTM C 1104 Moisture Sorption 0.03%

Dimensional Stability

ASTM C 356 Linear Shrinkage <0.4%

Thermal Conductivity

ASTM C177

	BTU.in/hr. °F.ft^2 (W/m.K)
25°F (-4°C)	0.221 (0.0318)
75°F (24°C)	0.239 (0.0345)
100°F (38°C)	0.253 (0.0365)
200°F (93°C)	0.299 (0.0432)
300°F (149°C)	0.350 (0.0504)
400°F (204°C)	0.383 (0.0553)
500°F (260°C)	0.464 (0.0669)
600°F (316°C)	0.549 (0.0792)
700°F (371°C)	0.660 (0.0952)

Thermal Resistance

ASTM C 518
(C 177) R-value/inch @ 75°F, 4.2 hr.ft^2.F/Btu (at time of Mftr). RSI value/25.4 mm @ 24°C 0.74 m^2K/W.

Corrosion Resistance

ASTM C 665 Corrosiveness Passed.

*ASTM C 795** Stainless Steel Stress Corrosion Specification as per Test *Methods C871 and C692:* U.S. Nuclear Regulatory Commission, Reg. Guide #1.36: U.S. Military Specifications MIL-I-24244 (all versions including B and C). Conforms
*"Provisions for lot testing may be required, consult manufacturer."

Compressive Strength

ASTM C165 at 10% 720 psf (34.4 kPa)

Figure K.2. Mineral wool material properties

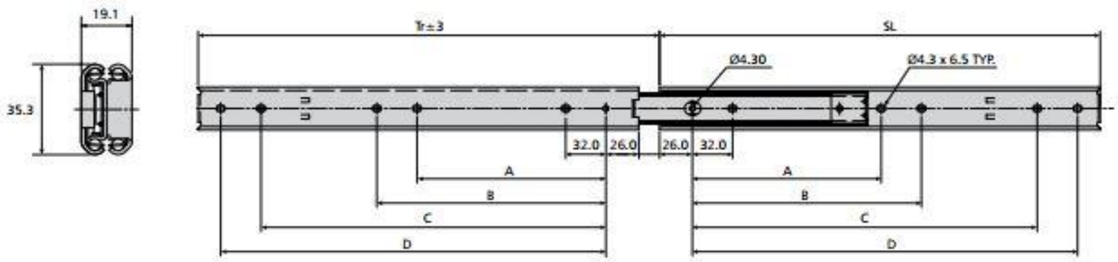
DS3031

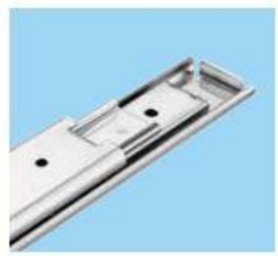
- Suitable for use in temperatures up to 300°C
- Load rating up to 80kg
- 100% extension
- 19.1mm slide thickness
- High temperature food-grade grease
- High grade stainless steel

- Para temperaturas de hasta 300ºC
- Capacidad de carga hasta 80kg
- 100% extensión
- Espesor de la guía de 19,1mm
- Lubricante de grado alimentario resistente a temperaturas altas
- Acero inoxidable de alta calidad

- Adatto per utilizzi fino a 300 gradi C
- Portata fino a 80kg
- Estrazione 100%
- Spessore guida 19,1mm
- Grasso per alta temperatura food-safe
- Acciaio inossidabile di alta qualità

Stainless steel
Acero inoxidable
Acciaio inossidabile





DS3031	mm						kg	
	SL	TR	A	B	C	D	W	L
DS3031-0030	300	317.4	-	-	224.0	256.0	1.53	65
DS3031-0035	350	366.6	-	-	256.0	288.0	1.72	70
DS3031-0040	400	415.8	-	192.0	320.0	352.0	1.91	75
DS3031-0045	450	465.0	-	224.0	352.0	384.0	2.10	80
DS3031-0050	500	514.2	256.0	288.0	416.0	448.0	2.29	75
DS3031-0055	550	563.4	288.0	320.0	480.0	512.0	2.48	70
DS3031-0060	600	612.6	320.0	352.0	512.0	544.0	2.67	65
DS3031-0065	650	661.8	320.0	352.0	576.0	608.0	2.86	60
DS3031-0070	700	711.0	352.0	384.0	608.0	640.0	3.05	55

Notes:

- *Fixing recommendation: M4 screw*
- *Max. head. ht. 2.5mm/Ø9.6mm*
- *Load ratings quoted are the maximum for a pair of side mounted slides installed 450mm apart, unless otherwise stated. For more information go to page 169 of the catalogue*
- *Please refer to 2D CAD drawings for dimensional tolerances*

Notas:

- *Recomendaciones de montaje: tornillo M4*
- *Altura máxima de la cabeza 2,5mm/Ø9,6mm*
- *Sin precisión adicional, la capacidad de carga máxima corresponde a un par de guías montada verticalmente y con una distancia entre ellas de 450mm. Para mas información, consulte la pagina 173 del catalogo*
- *Por favor, miren el dibujo 2D para las tolerancias dimensionales*

Note:

- *Consigli per il fissaggio: vite M4*
- *Altezza max. testa della vite 2,5mm/Ø9,6mm*
- *Le portate dichiarate sono il massimo per una coppia di guide montate di lato a 450mm di larghezza a meno che diversamente dichiarato. Per maggiori informazioni andate alla pagina 177 del catalogo*
- *Per le tolleranze dimensionali si prega di fare riferimento ai disegni 2D CAD*

Figure K.3. Data sheet of Accuride slides

Appendix L : Construction of Final Design

Upon putting this design into production, we will be conducting a market test which involves making 1000 models of this design and seeing how it does in the market. Construction of this design begins with the inner oven. We will begin by stamping out a 13.31” x 10.31” x 0.025” sheet of aluminum. This will serve as the bottom face of the oven. With the bottom sheet stamped out, we will then cut four equal 0.31” x 0.31” pieces out of each corner as shown in figure 8 below.

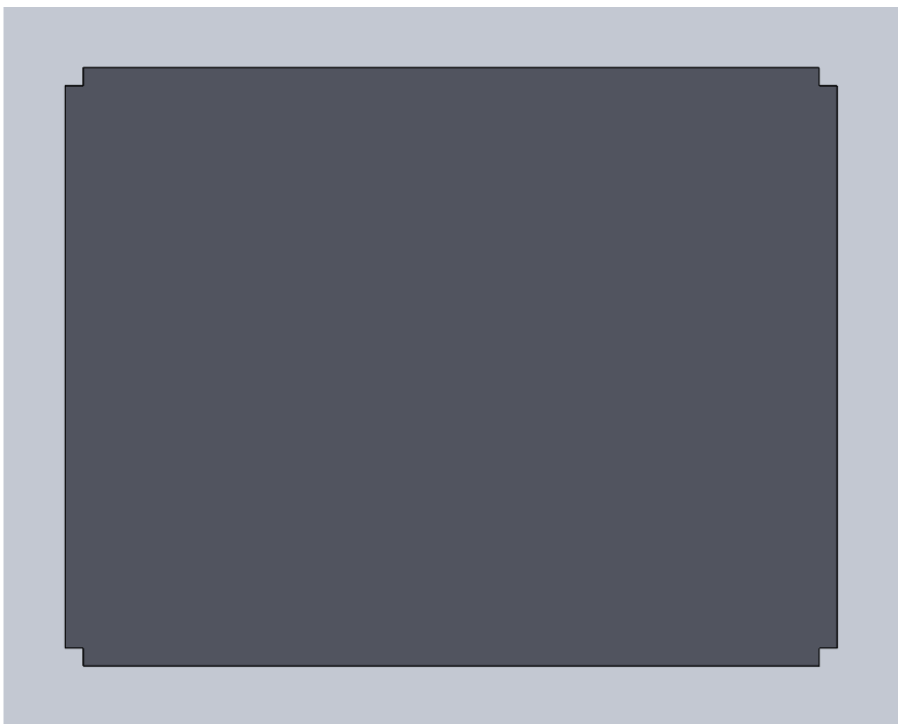


Figure L.1: Top view of oven bottom sheet with corners removed

These four corners are where the four vertical structural supports of the frame will be placed. Each support will be 9.94” tall and have two, 0.033” x 0.075” grooves cut on adjacent corners and run down the entire length of the vertical supports. For example: the back right support will have one groove facing the front of the oven and another facing the inside, while the back left support will have one groove facing the front of the oven and another facing the front right support. The front left and right supports will only have one groove and they will be placed so it faces the rear of the oven (see drawing #6 for a detailed drawing of these parts). These vertical supports will be cut from a 2” x 24” x 0.040” bar of multipurpose 6061 Aluminum and milled

down to the desired thickness of 0.033”. Each groove will be created using an endmill. With the bottom sheet resting against a flat surface, these four supports will be set in place and tig welded to the base. Figure L.2 below shows the base of the oven with vertical supports added.

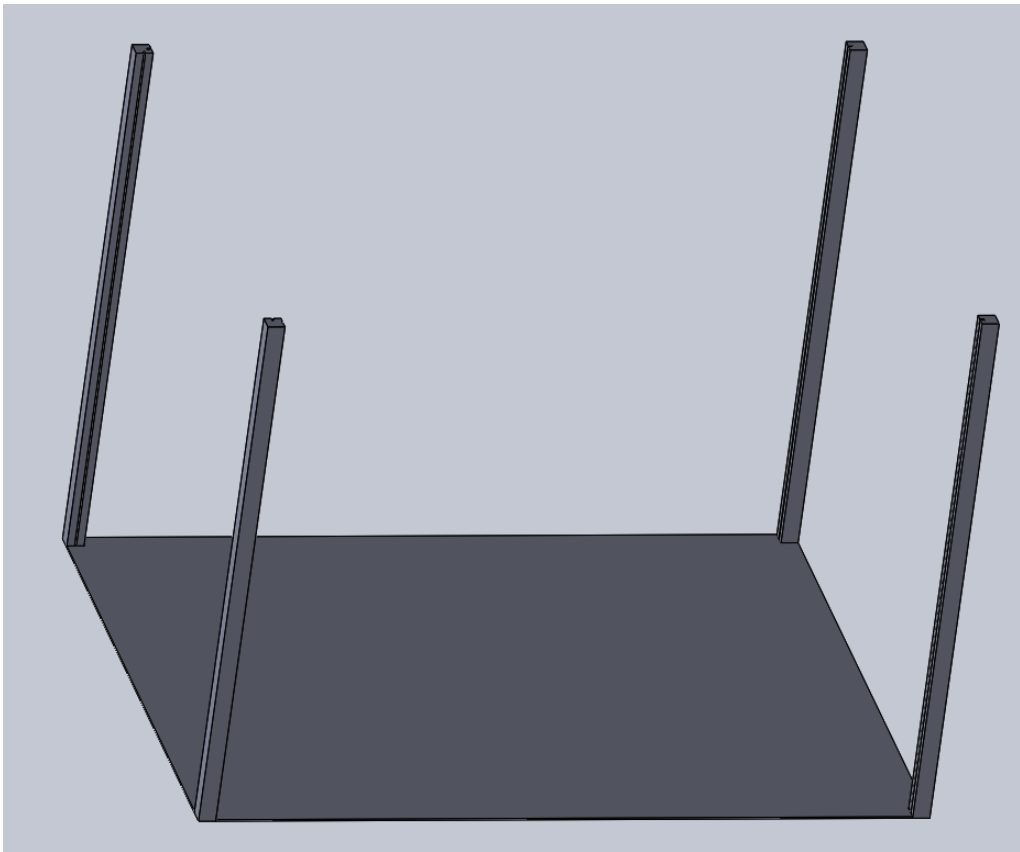


Figure L.2: Base of oven with vertical supports added

Once the vertical supports are in place, we can start creating and assembling the side walls of the oven. Three more sheet of 0.025” thick 6061 aluminum will be stamped out (two sheets of 12.84” x 10” and one sheet of 9.84” x 10”). The two 12.84” x 10” sheets will be inserted into the slits parallel to each other on the long sides of the oven while the 9.84” x 10” sheet will be inserted into the slits in the rear of the oven between the vertical supports. Figure L.3 below shows how these sheets will fit into vertical supports.

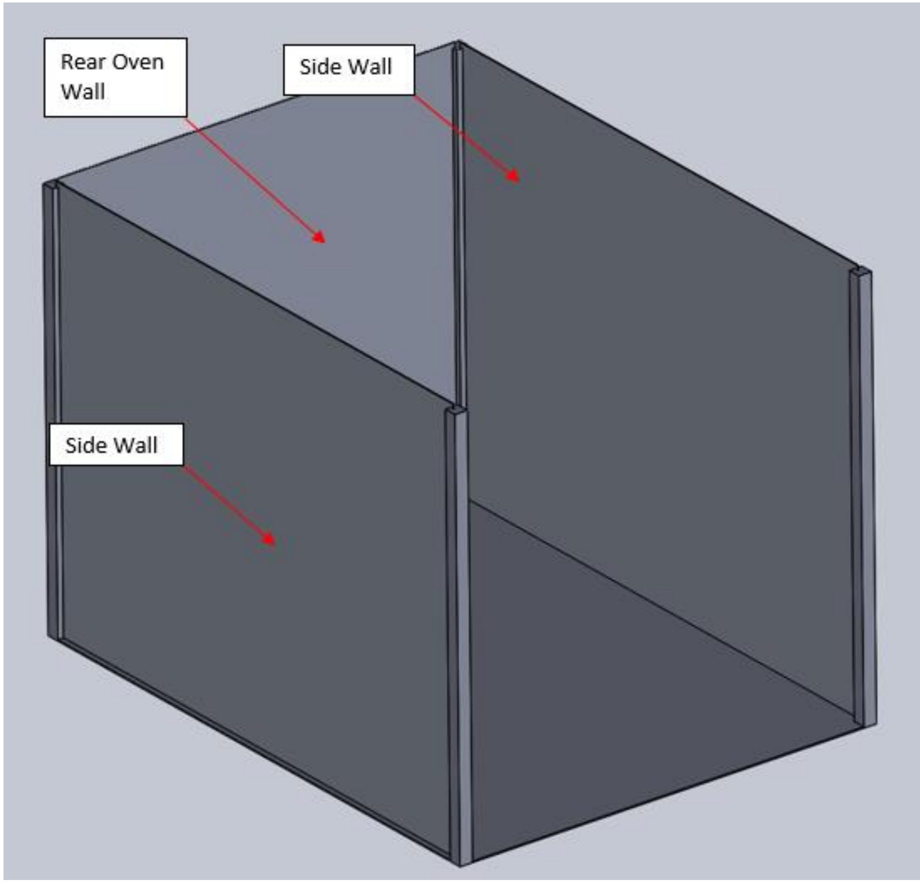


Figure L.3: Inner oven with supports and walls attached

The structural supports on the top of the oven will be similar to the vertical supports. They will be 13.31” x 0.31” x 0.31” rectangular aluminum pieces with a 0.22” chunk cut out of the corner for easy fitting with the rear support on top. Each support will also include a 0.03” x 0.1” groove for easy placement of the top sheet of the inner oven. The groove on the top, side supports will end 0.23” from the end of the rod which will give the top sheet a place to rest while the back support has the groove running all the way through the part. The first step in putting these supports together is to place the rear support so the rear oven wall fits into the groove and the ends of the part rest on the corner support pieces. Figure L.4 below shows what the corner support will look like before adding any top supports.

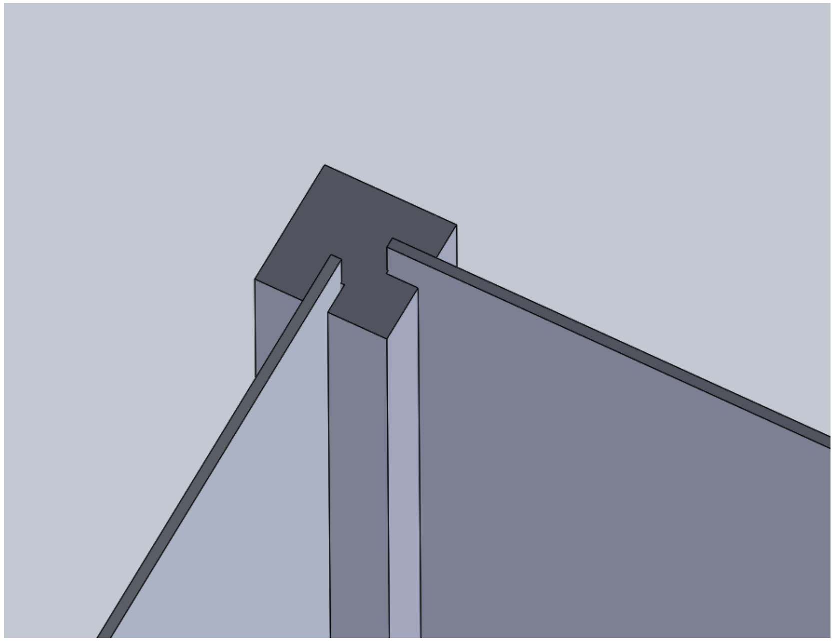


Figure L.4: Corner support with back, side walls and vertical supports added.

In figure L.5 below, we show how the top rear support should be added. With the back wall of the oven in place, the "L" shaped cut should be facing the front of the oven.

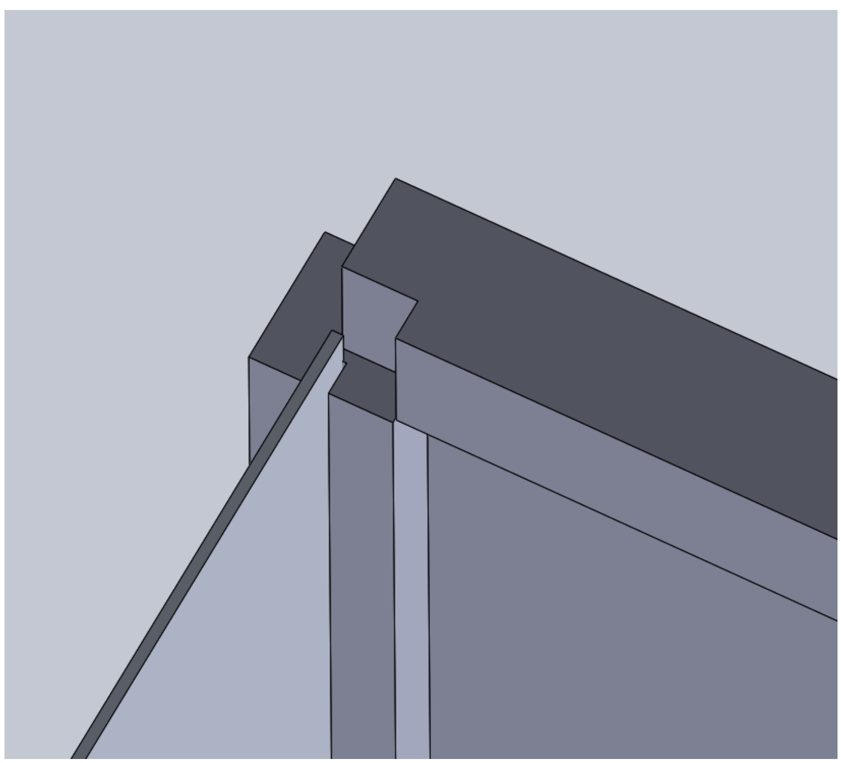


Figure L.5: Top rear support added to back oven wall

The next step is to add the top left and right supports. These supports will be placed similarly to the rear piece in which the side walls should sit in the groove of the part with the “L” shaped piece facing inwards and interlocking with the existing rear support. These two supports must be added simultaneously because of the 0.1875” round support that spans between these two parts. In each of these supports there is a tapped hole which the circular support must fit into. With the round bar in its place, the two supports can be set in place. Figure L.6 below shows how these support should be set in place in relation to the existing rear support.

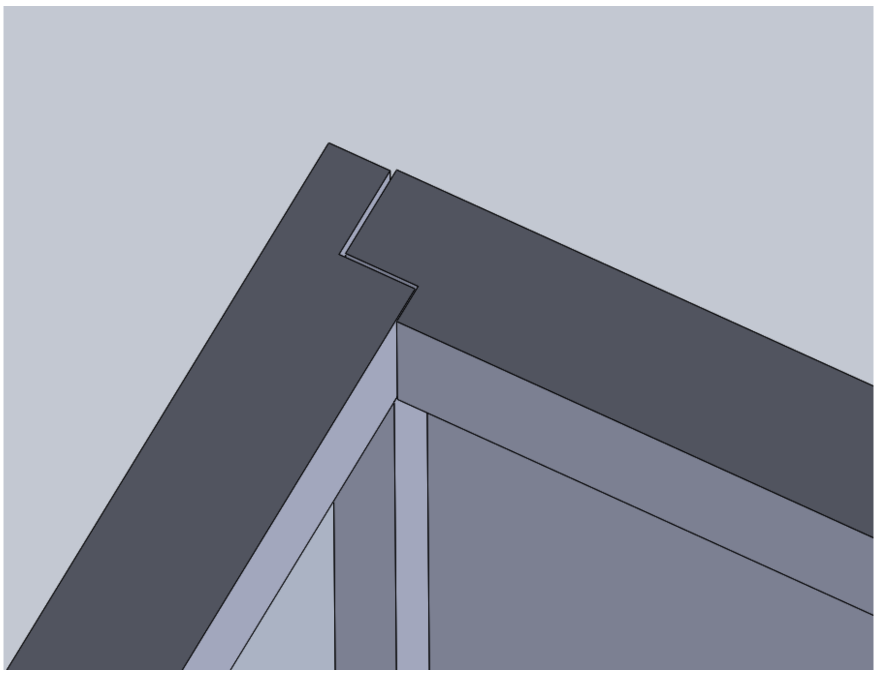


Figure L.6: Top side support added to side oven wall

After these top supports are in place, the final piece of the inner oven can com into place. We will stamp out one more sheet of 6061 aluminum (10.31” x 13.15” x 0.025”) and tig weld it to the top supports to make the roof of the oven. The finished product of the inside oven will look like figure L.7 below.

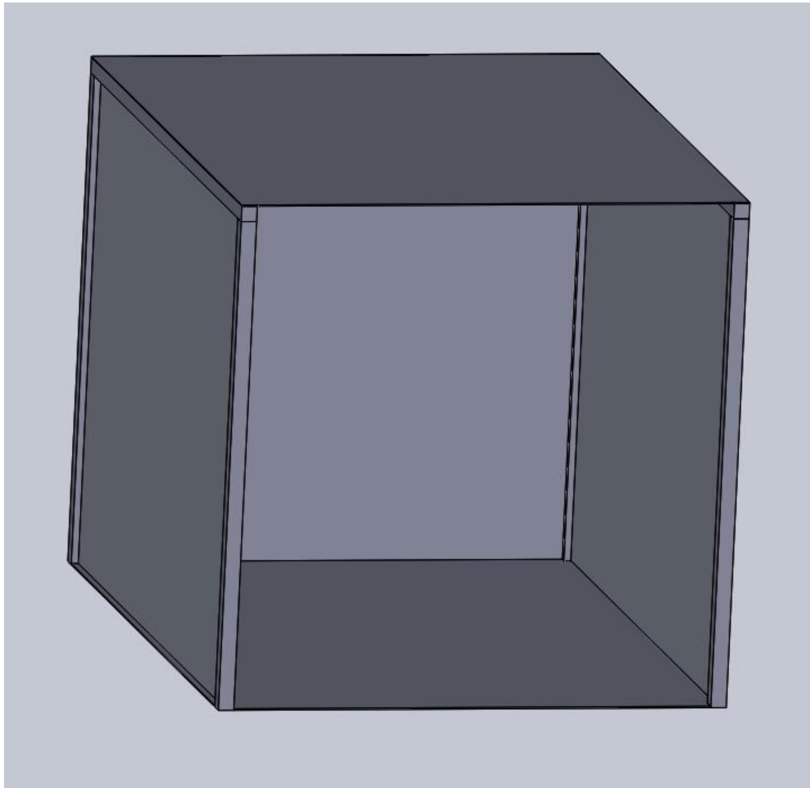


Figure L.7: Inner oven assembly

At this point, the oven will be a five-sided aluminum box with a reinforced frame. The next step is to insulate it. Using a bandsaw, we will cut two strips of ½" thick Microtherm insulation (45.16" x 1"). One strip will be wrapped and glued all the way around the edge of the box with the edges of insulation flush with the front face of the oven. This will be repeated for the remaining strip except it will be glued flush against the back face of the oven. The glue that will be used is 81160 High -Temp glue, which has a rated temperature range of 650 degree Fahrenheit and can be purchased online for around five dollars. Gluing the insulation to the outside of the aluminum box is only meant to keep it in place until the outer shell is added. Next, the team will obtain a 1" thick, 12" x 24" sheet of High Temperature UMHW Polyethylene from McMaster-Carr and cut it into eight strips using a bandsaw (two strips of 15.31" x 2" and two more 11.27" x 2" strips. These strips will be glued to the outside of the existing Microtherm insulation and perpendicular sides will be glued together. This hard plastic will serve as structural support for the outside box as well as an anchor point for other components to be screwed into without thermal bridging.

Next, the team will obtain a sheet of mineral wool and cut four, 2.5” thick sheets (two sheets of 11.26” x 15.31” and two sheets of 11.26” x 11.27”). These sheets will serve as the main insulation of the solar cooker and will be placed along the outsides of each oven wall between the layers of Microtherm. The mineral wool will be secured to the oven walls with the same 81160 High -Temp glue that was used for the Microtherm and Polyethylene sheets. Although the glue will not melt at any point during operation, this glue is only meant to be a placeholder for the mineral wool until the outer shell is added. Figure L.8 below shows how the Microtherm, Mineral Wool and Polyethylene will be assembled on the inner oven.

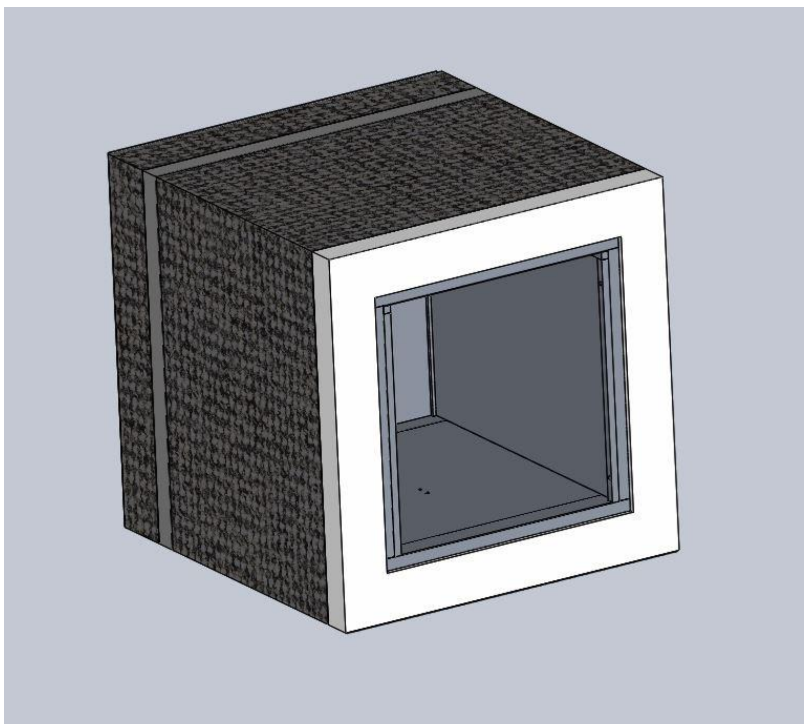


Figure L.8: Inner oven with Microtherm, wool and Polyethylene plastic added

The team will then obtain a 0.31” diameter oven gasket, which will be purchased from Davlyn and cut a 40” sheet. This oven will be glued around the inside edge of the cooker where the oven base and drawer meet with EP42HT-2FG epoxy. We decided to use this product because it is serviceable up to 450 degrees and it is FDA approved, which is critical because it will be in close proximity to the user’s food. This oven gasket will reduce the amount of heat lost through the crack where the body and the drawer meet. We have also decided to add another layer high temperature silicon as a gasket to protect from further heat loss. We will obtain a sheet of 0.06”

thick high temperature silicon and cut it into four strips (two strips of 0.25” x 11.75” and two strips of 0.25” x 12.31”). These strips will then be glued into place centered around the oven opening using the same epoxy that was used on the oven gasket.

To create the outer shell of the oven, the team will stamp three sheets of 0.025” thick 6061 aluminum and drill holes appropriately. For dimensions and hole callouts, see drawing #18 for the detailed drawing of outer back plate, drawing #1ABC for the detailed drawing of three walled outer box for dimensions, and drawing # 6 for the detailed drawing of the outer floor plate. The two, 2” protruding pieces of sheetmetal, will be bent 90 degrees to create a flange. Next, 2” from each of the long ends will be bent 90 degrees to create two more flanges, giving this piece of sheetmetal four total flanges. This sheetmetal will then be bent 15.38” from each end with the flanges facing towards each other. This three-sided piece of structure will be serve as three of the outer faces of the oven. A figure of the three-sided exterior is shown in figure L.9 below.

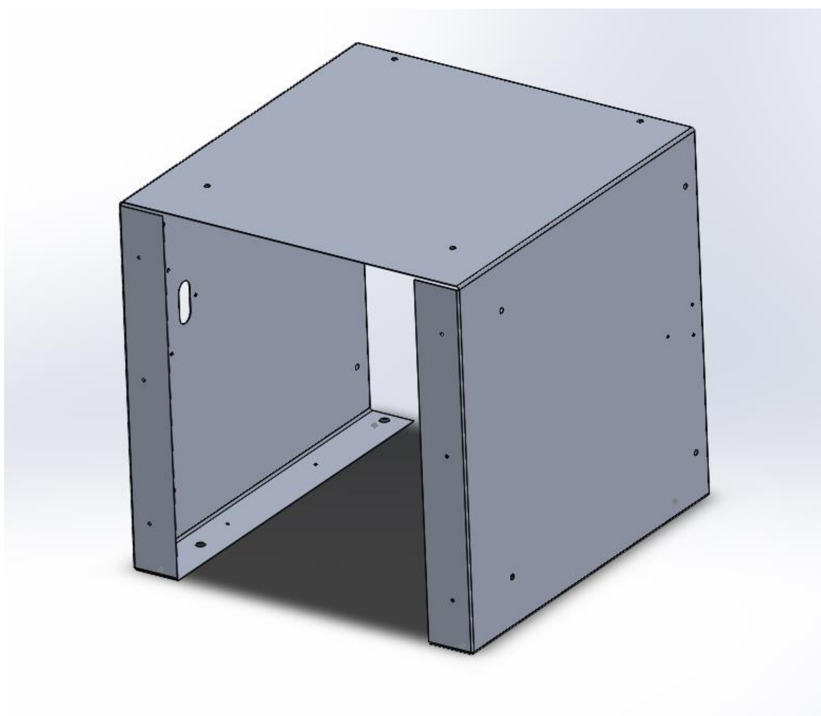


Figure L.9: Three sided outer shell with bottom and rear flanges

With this three-sided exterior folded in the correct shape as shown above, it can then be added to the oven. Starting with the rear of the oven moving to the front, we will grab the two sides of the oven and slide it forward over the insulation and Polyethylene. Since the aluminum is so

thin, it can be slightly bent outwards or wiggled to fit over any protruding pieces of insulation or plastic. Now, the inner oven with plastic and insulation should be completely covered on three sides by sheet metal as shown in figure L.10 below.

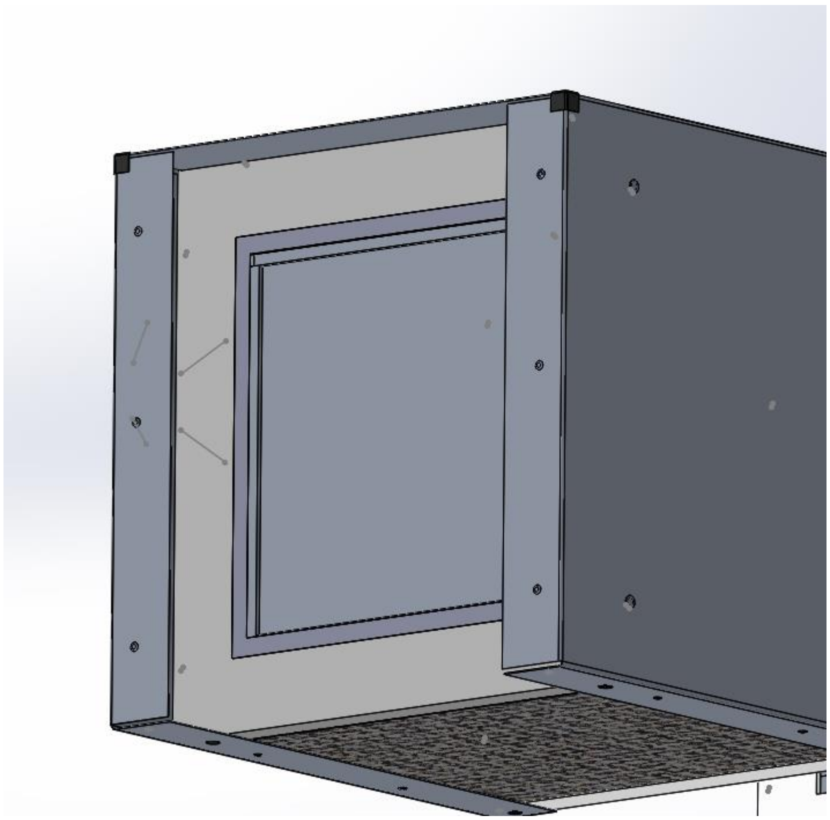


Figure L.10: Rear view of the inner oven with the three sided shell added. Note the carpet-looking material on the bottom is the mineral wool insulation.

The next step is to add the outer floor plate. With the piece of sheet metal stamped in the previous step, it will be inserted in between the insulation and the bottom flanges. Starting from the front of the oven and while pushing upwards on the insulation, the outer floor plate can be inserted. The bottom flanges can be slightly bent upwards to assist the floor plate while it is being inserted. The plate will be pushed back until the holes match with the bottom flanges. Figure L.11 below shows the bottom of the oven before the floor plate is added and figure L.12 shows how the floor plate is added.

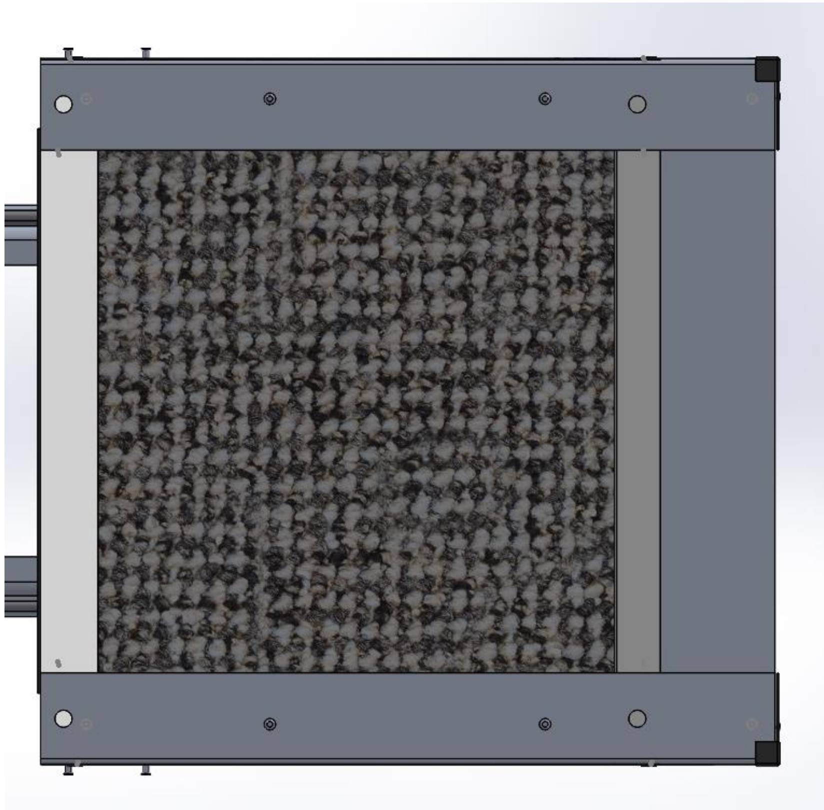


Figure L.11: Bottom view of the oven with exposed insulation. Note the “carpet” looking material is actually mineral wool insulation.

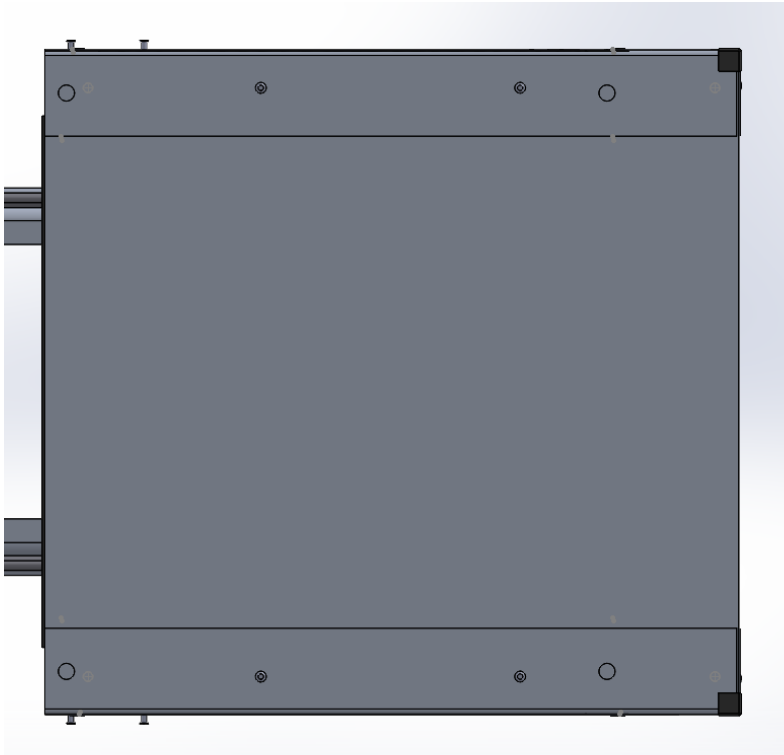


Figure L.12: Bottom of the oven with floor plate added and fastened to bottom flanges**.**

The back plate can be added in a similar manner to the bottom plate. Starting from the top, the plate can be inserted, bending the flanges as needed until the plate is fully inserted and the holes match with those on the rear flanges. This can be shown in figure L.13 below.

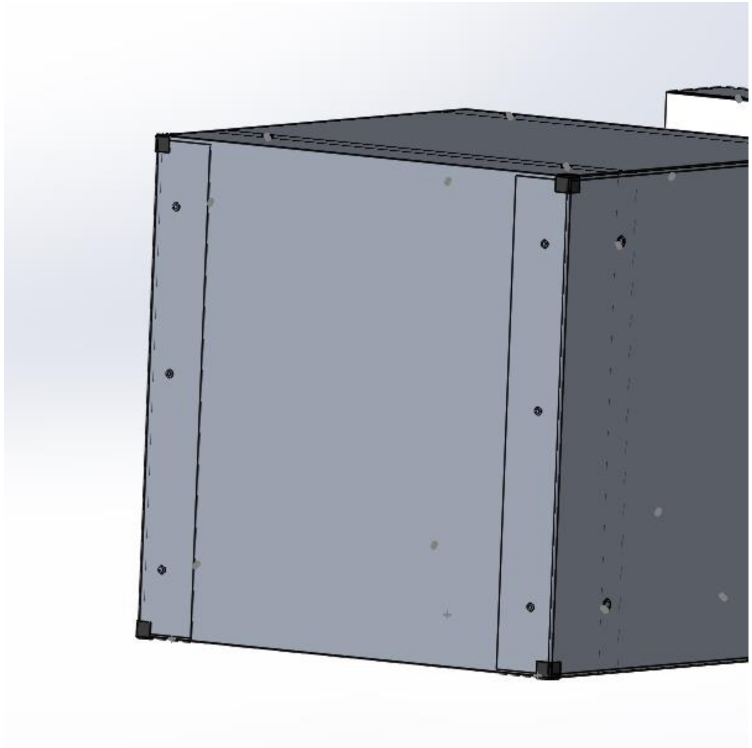


Figure L.13: Back of the oven with the back plate inserted and fastened to the outer flanges

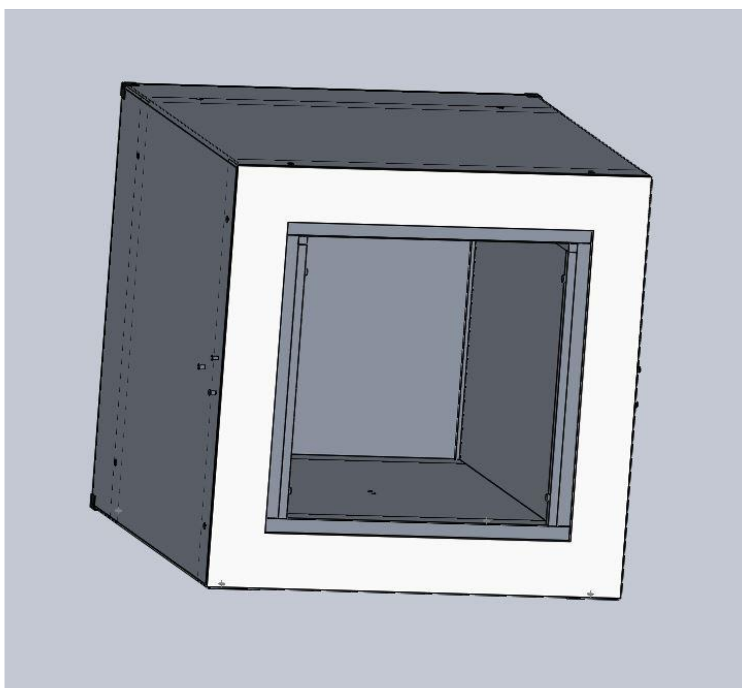


Figure L.14: Fully assembled inner and outer walls of the oven encompassing the white Polyethylene

With the body of the oven complete, we will then add the two gaskets that will come into play later when the drawer is assembled. First, the team will obtain a 0.38” diameter oven gasket and cut it into a 40” strip.

At this point, the body of the oven will be fully assembled and we will move on to the drawer portion of the cooker. The team will create two more drawer supports like the ones previously described in the inner oven assembly (see drawing # 11 for a detailed drawing of the drawer supports) and two thin drawer sheets to hold the face of the drawer in place. The small groove in the middle will be created using an endmill as described earlier For assembling this drawer, the team will start with the two supports laying flush on a flat surface with the grooves facing each other. On of the thin drawer sheets will be placed in the grooves between the two supports as shown in figure L.15 below.

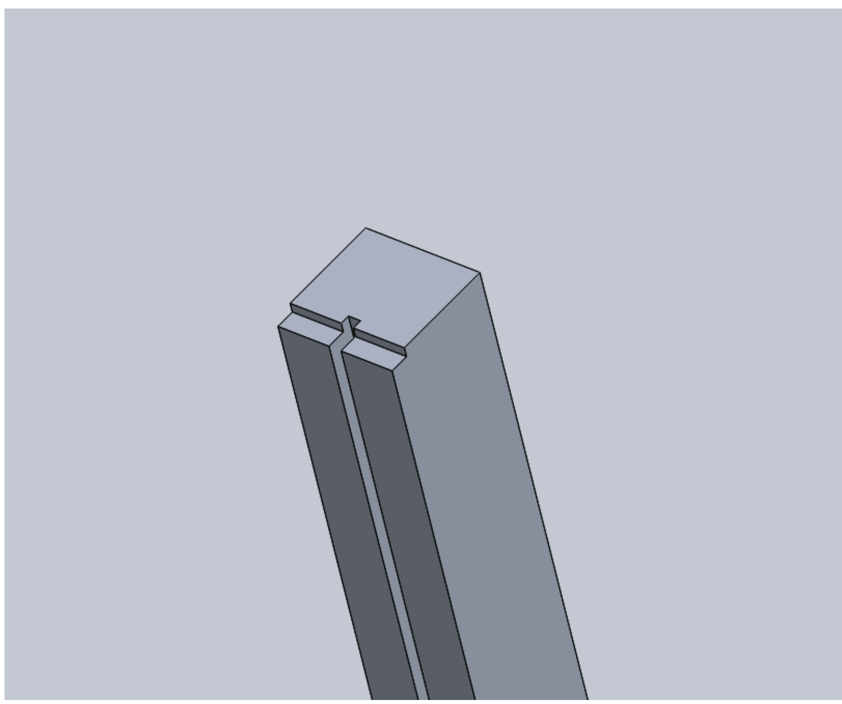


Figure L.15: One of the drawer supports with the fitting groove facing inside.

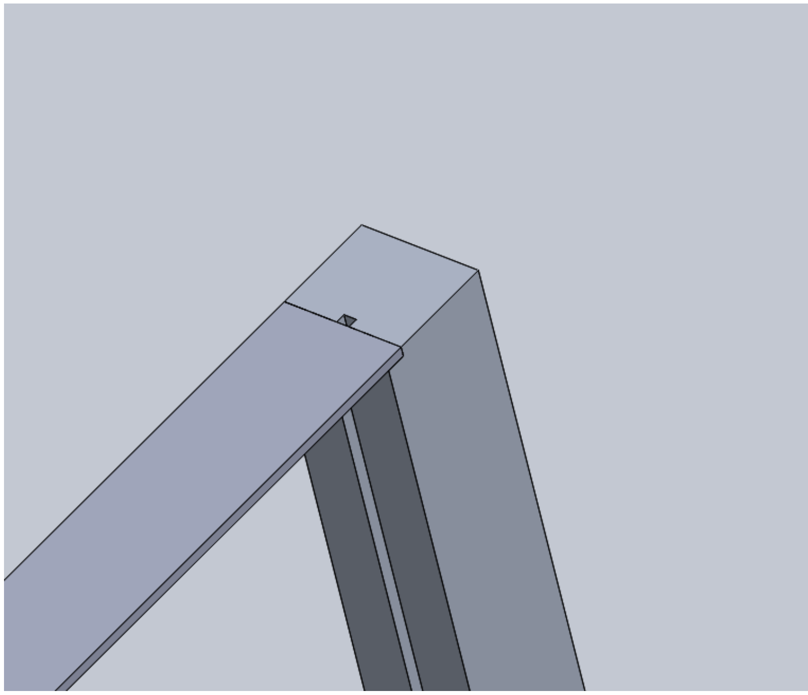


Figure L.16: Drawer support with the drawer sheet fit into the groove. Note the other side of the drawer support is not shown.

Once these pieces are in place, the intersection can be TIG welded to confirm a tight seal. Next, the front drawer sheet will be added the same way as the inner walls of the oven; by sliding the sheet through the grooves of the supports. When the sheet is fully inserted, the top drawer sheet can be tig welded on the other side of the drawer supports in the grooves (same as the other side) to trap the drawer face in place. This drawer face will be left with some wiggle room inside the support grooves to account for thermal expansion (this is explained in the Analysis portion of the report). Next, a strip of 0.31” x 0.5” x 92.84” Microtherm will be cut and wrapped around the assembled drawer supports and sheets as shown in figure L.17 below and glued in place. This strip of Microtherm will be offset from the edge of the drawer sheet by 0.5”. This is because we are adding another layer of 0.025” aluminum as a cover for the microtherm so it isn’t exposed to the food. Outside the Microtherm, we will add more Polyethylene plastic to provide structural support and prevent thermal bridging. Using a bandsaw, pieces will be cut following in the same procedure and dimensions as described earlier for the inner oven assembly. With the Polyethylene pieces glued to the microtherm, it will look like figure L.17 below.

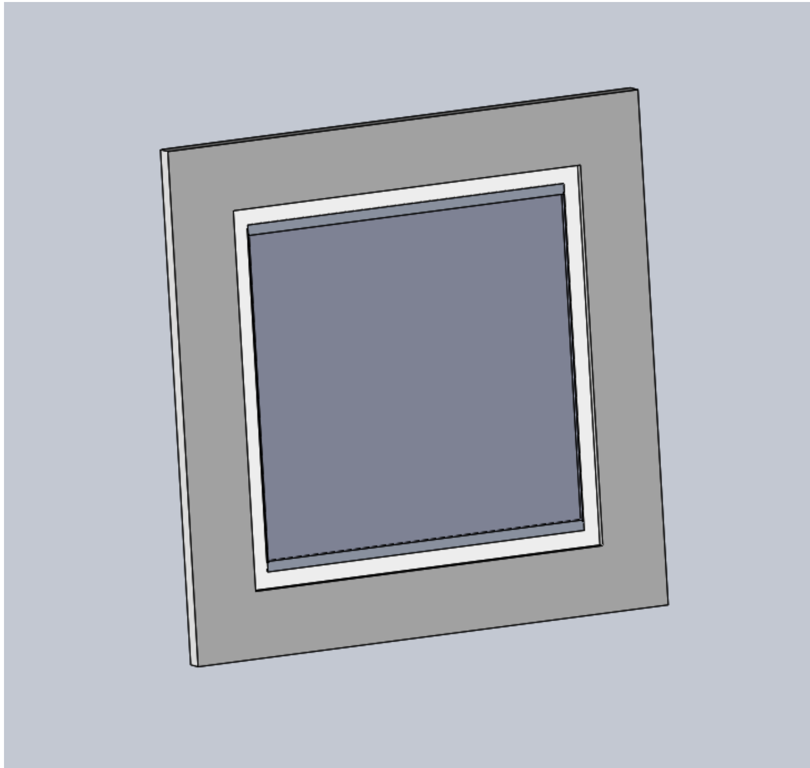


Figure L.17: Drawer face with Microtherm (white) and Polyethylene (light gray) added

With the Polyethylene added, now we will cover the microtherm. By cutting four more strips of 0.025” 6061 aluminum (two pieces of 0.52” x 11.31” and two pieces of 0.52” x 10.27”) we can begin to create the Microtherm cover, which will protect the food from being in direct contact with the insulation. The strips will be placed along the Microtherm so the face of the strips sit flush with the drawer supports. These will be tig welded along the inside edges to the drawer supports to create a strong seal. Microtherm insulation is fireproof and will not be damaged by the heat from welding aluminum. With the insulation cover added, the drawer face will look like figure L.18 below.

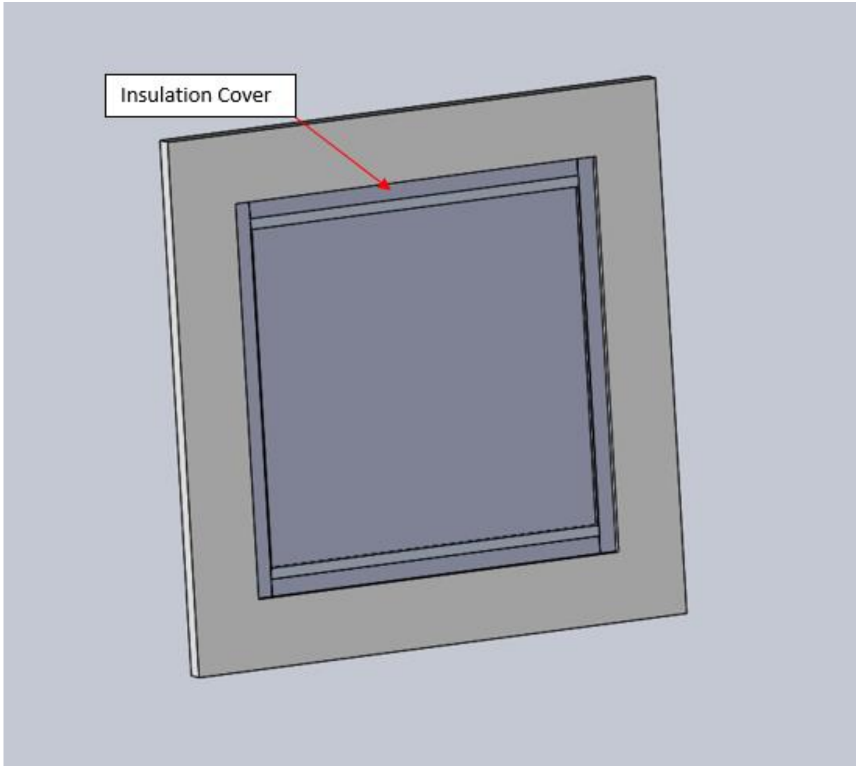


Figure L.18: Drawer face with insulation cover added.

After the inside face of the drawer is complete, we will add 2" of mineral wool insulation and glue it to the backside of the face (the side of the drawer that includes the exposed microtherm. The rest of the drawer is simply an aluminum box attached to the drawer face, encompassing the insulation. To create this box, the team will stamp and drill five pieces of 0.025" thick 6061 aluminum (two pieces with the dimensions 15.30" x 2.98" for the drawer sides, two pieces with the dimensions 15.39" x 2.98" for the drawer top and bottom, and one piece with the dimensions 15.36" 15.27" for the drawer back). With the drawer back laying flush against a flat surface, the two side pieces can be tig welded to the back piece, parallel to each other along the seam. The same will be done for the top and bottom pieces and they will also be tig welded to the side pieces along the vertical seam. With the drawer back completed, it will look like figure L.19 below.

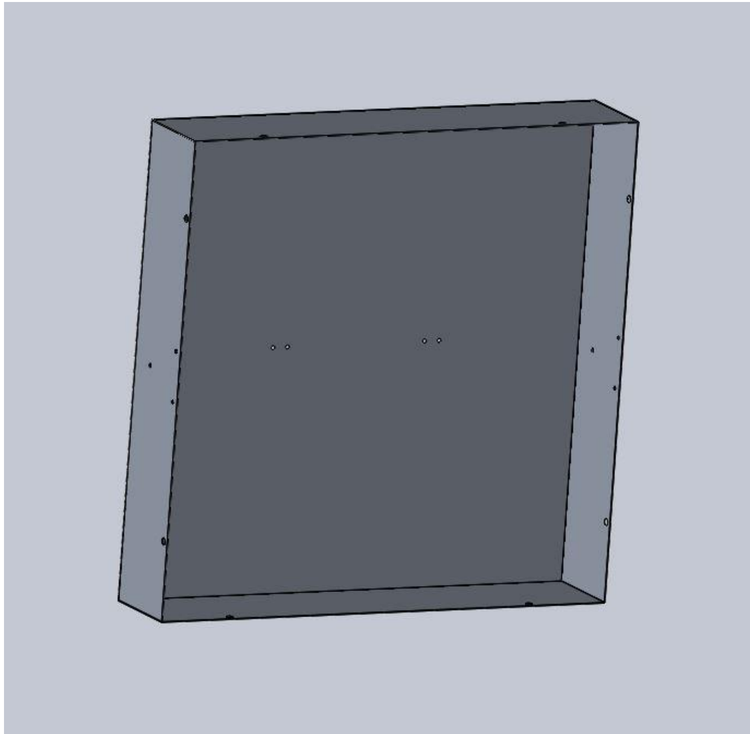


Figure L.19: Back of the drawer which fully encompasses the wool insulation on the back of the drawer.

Next, we will place the drawer back over the insulation until it sits flush with the front face of the Polyethylene. The aluminum drawer back will be screwed into the plastic with eight screws as shown in the bill of materials (two on each face). The completed drawer is shown in figure L.20 below.

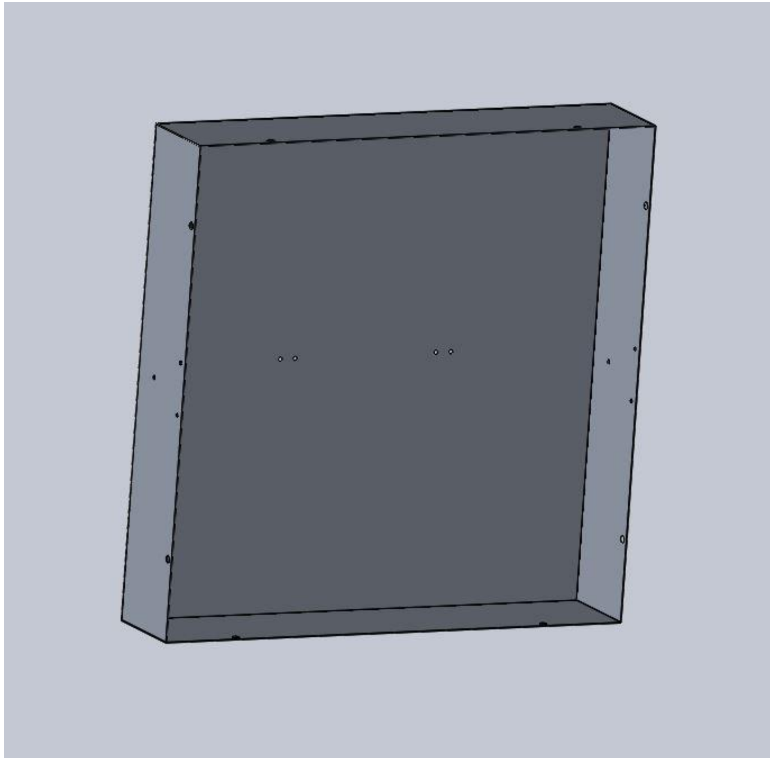


Figure L.20: Full assembly of the drawer with front face, insulation, and aluminum back.

Finally, the two pieces of the cooker need to come together. For each solar cooker, we will purchase one set of Accuride Corrosion Resistant slides. Theses are rated for over 100 pounds and are meant for high temperature applications which makes them ideal for our design. Each slide requires six #8 pan head screws (three for each part of the slide). The slides will be assembled to the inside wall of the oven via the instructions provided with the Accuride slides.

To create the grease protectors for the drawer slides, we will start with two sheets of 6061 aluminum (specific dimensions of this part can be found in drawing #1C, drilling as necessary) and create a 45 degree bend, 0.5 inches from the top of each sheet. These will serve as a protector for any excessive grease or splatter that may result from using the product. Next, a 90 degree bend in the opposite direction will be made 0.3 inches from the bottom of each sheet. This bottom bend is where the cooking rack will rest. At this point, the aluminum grease protectors will look like figure L.21 below.

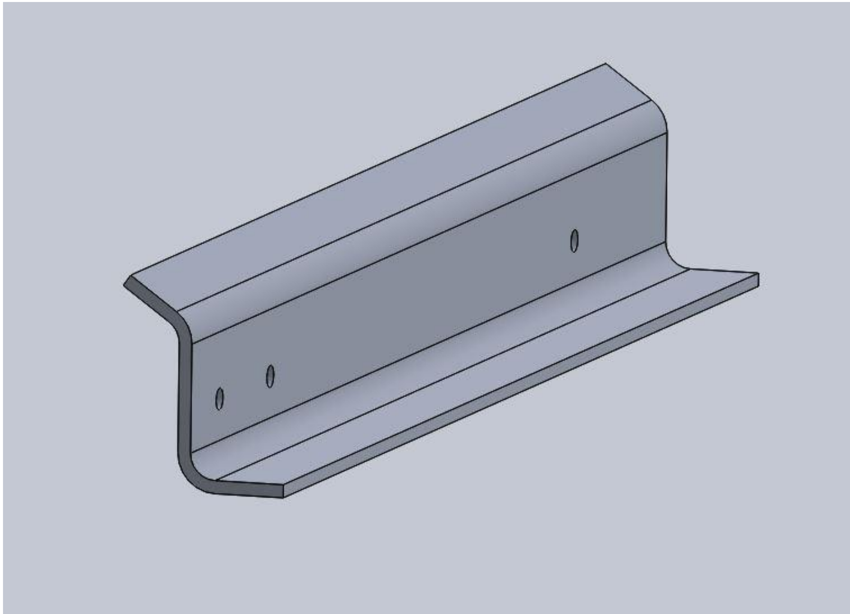


Figure L.21: Grease protector for one of the drawer slides. In this case, the given grease protector would be used for the left drawer slide.

After the drip projectors are created, they can be assembled to the rest of the oven. With the 45 degree bend facing the outside of the oven (and the 90 degree bend facing the inside of the oven), the drip protectors will be lined up with the inside portion of the drawer slides until the tapped holes match. Next we will obtain the two “L” brackets and place them on the outside of the drip protectors so the holes match up and the “L” shape is pointed towards the outside. With all the holes matched up, we can then bolt the pieces together. The L brackets, drip protector and drawer slide will be secured together with two bolts for each slide (see drawing #1C for hole callout) while the third bolt goes through the opposite side and secures the drawer slide to the drip protector. The two pieces of the drawer slides are fully assembled and now they need to be attached to the drawer face. With the drawer laying flat and the drawer face upwards, each “L” bracket (with attached slide) will be tig welded along the long seam of the bracket to the drawer support. Figure L.22 below shows the drawer slides and grease protectors added to the drawer face. This will secure a strong bond between the drawer slides and the drawer. Now the oven body and drawer are complete and the internal components need to be added.

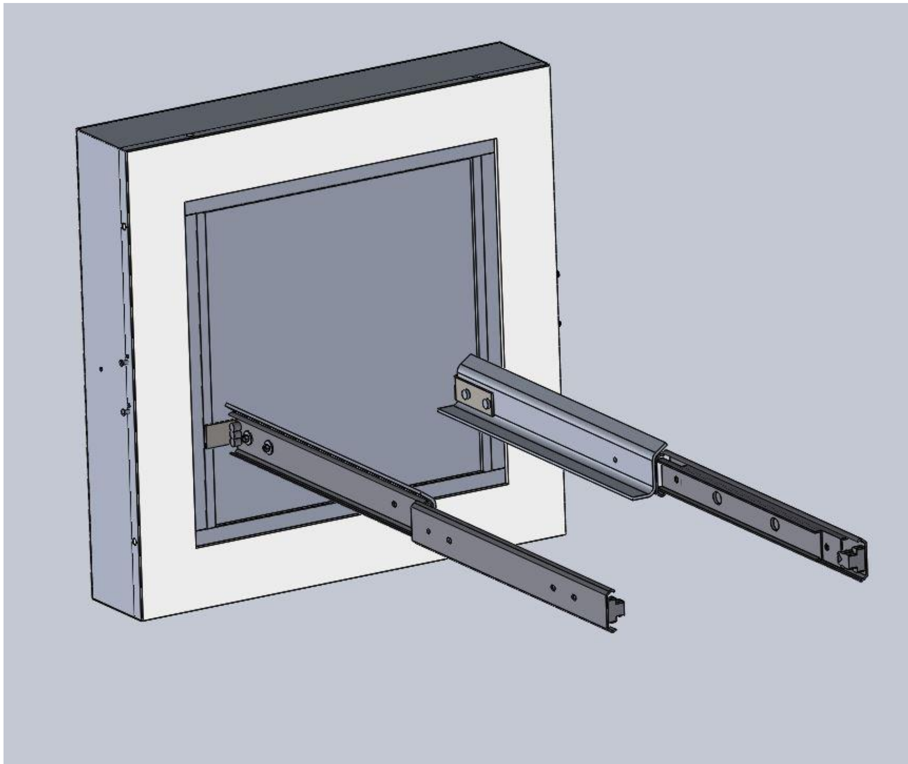


Figure L.22: Assembly of drawer face with drawer slides, grease protectors and L brackets attached.

Next, the team will attach the latches to seal the drawer. For this project, we have decided to use a latch action toggle clamp which can be purchased online for around five dollars. The latch side of this part will be placed on the left and right hand sides of the drawer with the base of the latch sitting flush with the inside drawer face (tapped holes in the drawer side will match with the latch). Each latch will then be screwed into place with two Delta PT 60 thread forming fasteners into the polyethylene. On the oven body, the clamping components of the toggle latches will be placed coincident with the latches on the drawer. Lining up the tapped holes in the oven body with the clamp holes (making sure to put the clamp arm facing towards the back of the oven), they can be screwed into the Polyethylene using the same Delta PT 60 thread forming fasteners. The team decided to use these fasteners because they are meant for ductile thermoplastics such as Polyethylene. With the latches added, the outside of the oven should look like figure L.23 below.

Still need: latch, nichrome wire, drawer handle, control system/housing, rubber feet.

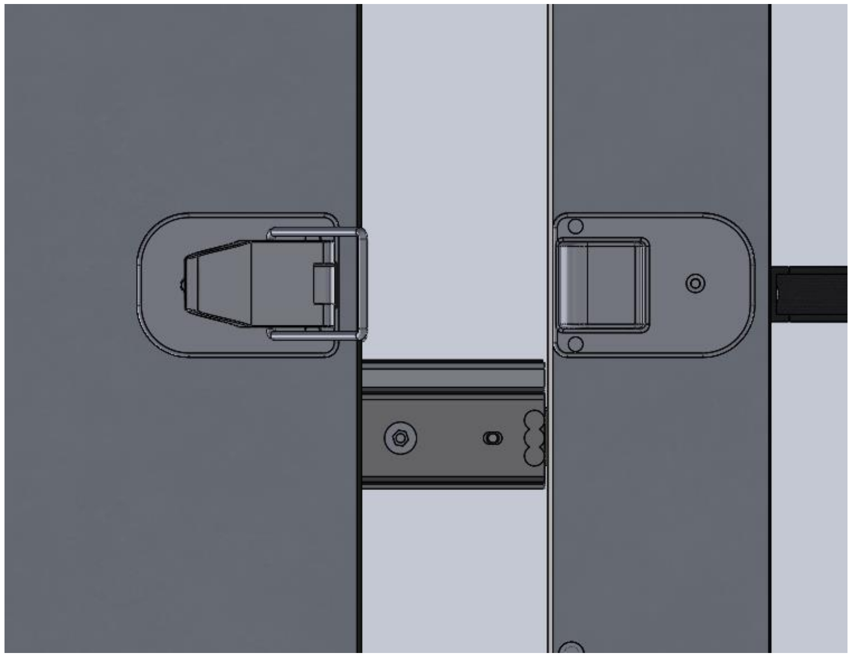


Figure L.23: Side view of the solar cooker with the latches attached. Note the “rod” in the middle is the drawer slide.

After the drawer latches are attached, the team will then add the nichrome burner. The specifics of the burner are shown in the bill of materials in drawing #Draw01 and can be purchased online. The burner will be placed atop two thin 0.025” thick sheets of aluminum which will be spot welded to the floor of the oven. The thin wires (which were left sticking through the small hole in the bottom corner from earlier in construction) will be attached to the positive and negative leads of the nichrome burner. On the outside wall of the oven, we will attach the Arduino Uno and relay as shown in figure L.24 below. This will be the control system which regulates the temperature inside our oven and it will be screwed to the outside wall of the oven.

Figure L.23: Arduino Uno and relay wiring in relation to the solar panel and nichrome burner

To create the control housing, the team will obtain another sheet of 0.025” thick 6061 aluminum and stamp it in the shape of a central square with four inverse trapezoidal pieces extending on each side. Each trapezoidal piece will be bent downwards until then intersect and they will be tig welded together along the seams. A small rectangle will be cut out of the square face and the 16X2 Character LCD Display will be inserted from the underside so the face of the display is outside the housing. The housing will then be secured to the outer box four 0.13” rivets. The control housing with LCD Display attached is shown in figure L.24 below.

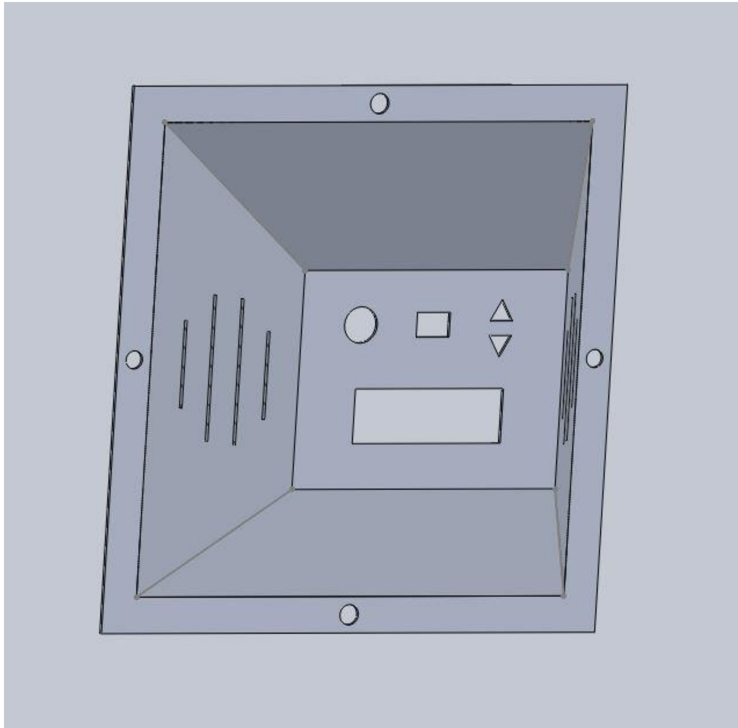


Figure L.24: Control housing attached to the outside wall of the oven

The final steps in assembling the solar cooker are to add a drawer handle and rubber feet. To open and close the drawer face, we have decided to attach a U-handle to the face of the oven. This handle will be attached to the face of the drawer with four 0.13” rivets as shown in figure L.25 below. We will also attach four, 2” diameter rubber pieces to the four bottom corners of the oven. These will serve to elevate the cooker and stop it from sliding on the floor.

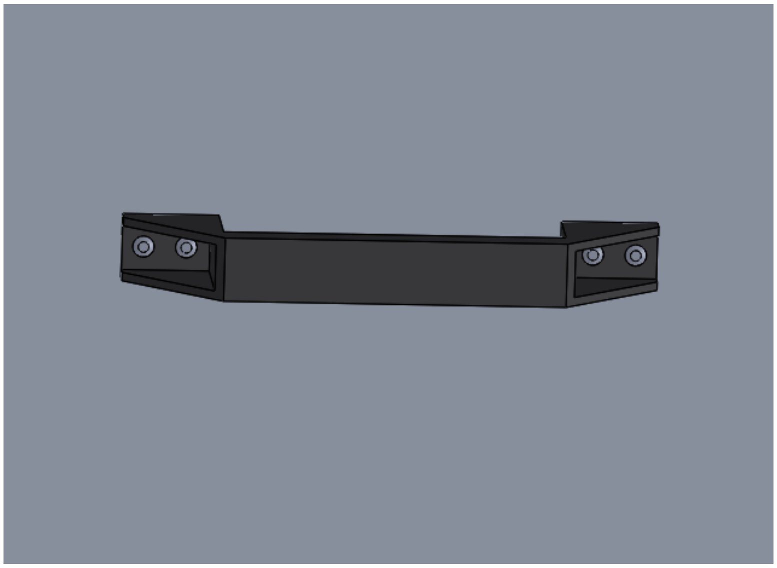


Figure L.25: Drawer face with handle attached

Appendix M: Cost Analysis

Table M.1. Cost analysis

Part	Description	Price [$]	Quantity	Total Price	Manufacturer
ELC EBL223	#12-14 Screw	$0.10	8	$0.80	Stanley Engineering
⅛ x ⅛ Pop Rivet	Pop Rivets	$0.05	18	$0.90	Grainger
18-8 Washer	Washers	$0.05	6	$0.30	Bolt Depot
STAN-PT-K40	K40 PT Thread Forming Screws	$0.20	12	$2.40	Stanley Engineering
HH-201	Toggle Clamp	$5.41	2	19.82	Toggle Clamp Store
ABS01	Drawer Handle	$1.40	1	$3.75	Home Depot
AP2624802	Oven Gasket	$23.48	1/2	$11.74	Whirlpool
Roxul-R22	Wool	$0.85	2.5	$2.13	
45929	Rubber Feet	$3.00	4	$12.00	Rockler
71-HT-60D-.032	Silicon Rubber Gasket	$93.00	1/8	$11.63	Shyde
8720K53	High Temp Polyethylene	$67.00	1	$67.00	McMaster Carr
ASTM B209	Aluminum 6061	$31.53	36 “ x 48”	$40.09	Online Metals
N/A	Arduino Uno	$10.00	1	$10.00	Arduino
660532	Burner	$ 7.75	1	$ 6.00	Thrifty
To be Decided which model	LCD Display	$2.50	1	$2.50	Uxcell
SS0330 - 12	Drawer Slides	$48.00	1	$48.00	Accuride

B-9100 SINT-NIKLAAS	Microtherm	$58.00	1/8	$ 7.25	Promat
XY-08467-24	Type K- High Temp. Thermocouples	$ 26.00	1/2	$13.00	Davis Instruments
N12196	Corner Protectors	$5.00	1/2	$2.50	Roving Cove
			Total Material Price	$ 261.81	

Appendix N: Arduino Code

```
#include <max6675.h>

int ktcSO = 8;
int ktcCS = 9;
int ktcCLK = 10;

int Relay = 6;

MAX6675 ktc(ktcCLK, ktcCS, ktcSO);


void setup() {
  Serial.begin(9600);
  delay(500);

pinMode(Relay, OUTPUT);
}

void loop() {
   basic readout test

   Serial.print("Deg C = ");
   Serial.print(ktc.readCelsius());
   Serial.print("\t Deg F = ");
   Serial.println(ktc.readFahrenheit());

   delay(100);

if (ktc.readFarenheit() < 125) {
  digitalWrite(Relay, LOW);
}
if (ktc.readFarenheit() > 125) {
  digitalWrite(Relay, HIGH);
}
}
```

Appendix O: Microcontroller and components

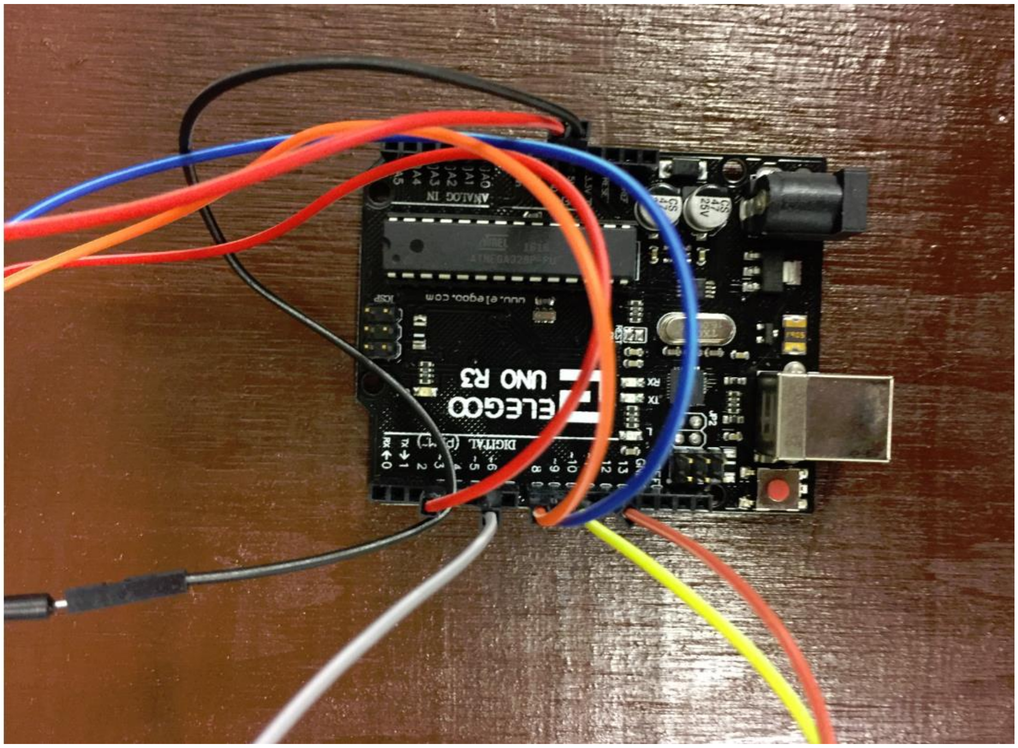


Figure O.1: Elegoo Uno microcontroller

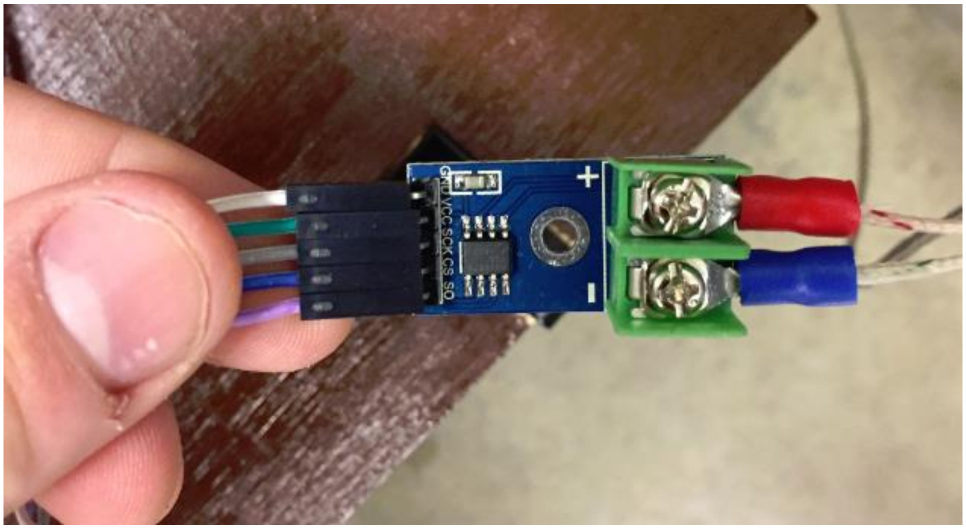


Figure O.2: Control Board for Thermocouple Type K

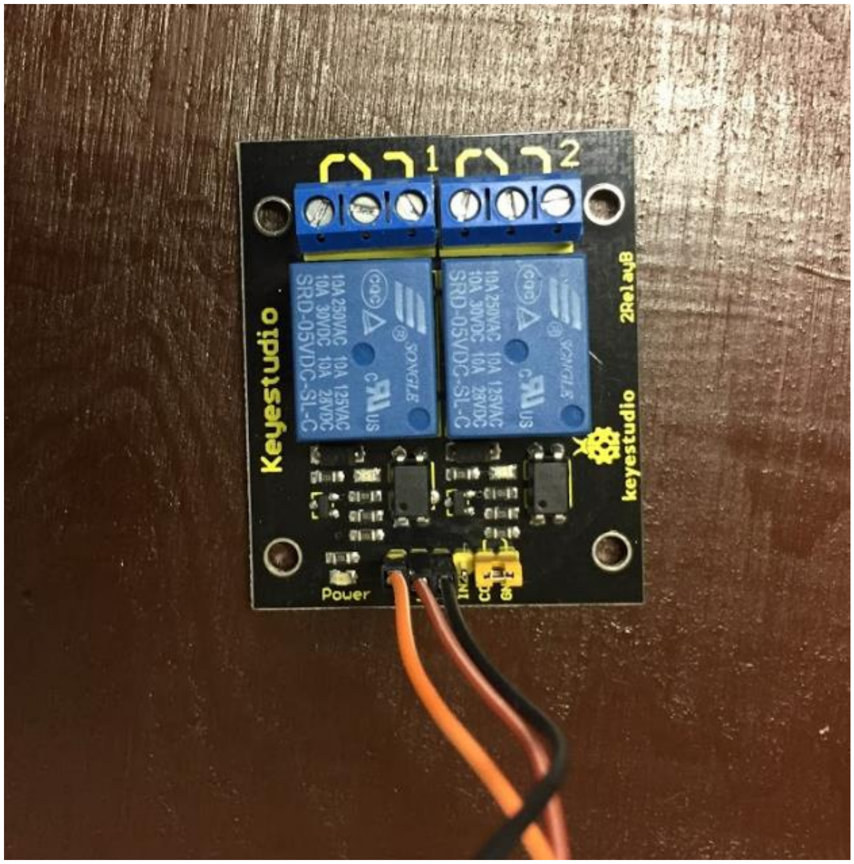


Figure O.3: Power relay connecting solar panel to Elegoo.

Appendix P

```
"Temperatures throughout an Oven"

T_inf = 700 [C] "temperature of nichrome wire"
T_amb = 25 [C]  "temperature of ambient air"

L_alu = 0.003175 [m] "thickness of the aluminium equal to 1/8 inch"
L_ins = 0.0508 [m] "thickness of insulation equal to 2 inches"
L_oven = 0.254 [m] "length of the oven ~ 10 inches"

A_heat = .0001 [m^2] "area of the heating element"
r = (A_heat/pi#)^.5 "radius of heating element"
A_1 = (L_oven)^2 "area of one surface of the oven"
A_5 = A_1*5 "area of all surfaces of the oven"

k_alu = 205 [W/m*K] "thermal conductivity of aluminium"
k_ins = 0.4 [W/m*K] "thermal conductivity of wool"

epsilon_alu = 0.09 [-] "emissivity of aluminium"
epsilon_iron = 0.31 [-] "emissivity of iron"

"Solving for convection coefficient of ambient air"
P = 101.3 [kPa] "ambient pressure"
h_amb = 20

"Coefficient of Convection for Inside Oven

T_air = (T_inf+T_inneralu)/2 average temp of inside the oven, temp of air
k_air = Conductivity(Air_ha,T=T_air,P=P)
mu = Viscosity(Air_ha,T=T_air,P=P)
beta = 1/T_air
alpha = ThermalDiffusivity(Air_ha,T=T_air,P=P)
Pr=Prandtl(Air_ha,T=T_air,P=P)
Ra_L = (g*beta*(T-inf-T_inneralu)*L_oven^3)/(alpha*mu)
Nu_L = 0.18*((Pr/(0.2+Pr))*Ra_L)^0.29
Nu_L = h_i*L_oven/k_air"

"Or Conduction of Air"

T_air = (T_inf+T_inneralu)/2
k_air = Conductivity(Air_ha,T=T_air,P=P)

"Radiation Exchange from heating element(1) to walls(2)"

sigma = sigma# "stefan-boltzmann constant"
4 * F_21 = f3d_21(L_oven,L_oven,L_oven, r, 0) "view factor from all walls to circular disk"
F_12 * A_heat = F_21 * A_5 "view factor from circular disk to walls"

R_rad = (1-epsilon_iron)/(epsilon_iron*A_heat) + 1/(F_12*A_heat) + (1-epsilon_alu)/(epsilon_alu*A_5)

"Resistances of Convection and Conduction"

R_cdair = L_oven/k_air "conduction from air"
R_cdalu = L_alu/k_alu "conduction from aluminium"
R_cdins = L_ins/k_ins "conduction from insulation"
```

R_cvair = 1/h_amb "convection of ambient air"

"Steady- State temperatures"

q_rad = (sigma*(T_inf^4-T_inneralu^4))/R_rad
0 = (T_inf-T_inneralu)/R_cdair+ (T_surface-T_inneralu)/(R_cdair+R_cdins) + q_rad
0 = (T_inneralu-T_surface)/(R_cdair+R_cdins)+(T_amb-T_surface)/(R_cvair)

Attachment Q- Transient Model Calculations

```
% This is a transient model for calculating the time at which a thermal
% storage heats up.

clear all
close all
```

Experimental Data

```
filename = 'Water boil with lid.xlsx'; % name of excel file containing the experimental data
sheet = 1; % the sheet where the data is located in the excel file
xlRange = 'A2:B98'; % the range of our data in the excel file
data = xlsread(filename, sheet, xlRange);
```

Variables

```
c_cement = 0.9; % [J/g-K] specific heat of cement
c_water = 4.187; % [J/g-K] specific heat of water
m_cement = 400; % [g] mass of structure (cement)
m_water = 1000; % [g] mass of water

% Power
Power_PV = 93; % [W] power of the solar panel

% Dimensions of the Structure (cylinder)
height = 10; % [inches]
width = 12; % [inches]
length = 10; % [inches]
SA_inches = width*height*2 + width*length*2 + length*height*2; % [inches^2] surface area of inner
box
SA = SA_inches * 0.0254^2; % [meters^2]

%Specifications of Insulation for Prototype
Pink_k_US = 1/13; % [h*ft^2*F/Btu] conductivity of pink insulation
Pink_k = Pink_k_US & (1/5.67826337); % [W/m^2*K]
MicroT_k = 0.03; % [W/m*K] conductivity of microtherm
MicroT_thickness_in = 0.5; % [inches] thickness of microtherm
MicroT_thickness = MicroT_thickness_in * 0.0254; % [m]
resistance = MicroT_thickness/(MicroT_k*SA) + 1/(Pink_k*SA); % [K/W] total resistance of box

%Resistance of Design
MT_thickness_US = 2;
MT_thickness= MT_thickness_US * 0.0254;
resistance2 = MT_thickness/(0.021*SA);

% Temperature Data
amb_temp = (data(1,2)-32)*(5/9); % [degC] ambient temperature
inside_temp = 210; % [degC] inside temperature of the cooker
water_boiling = 100; % [degC] temperature water boils
```

```
delta_boiling = water_boiling - amb_temp; % [degC] change of temp. of boiling water w/respect to
ambient temp
```

Thermal Storage Calculations

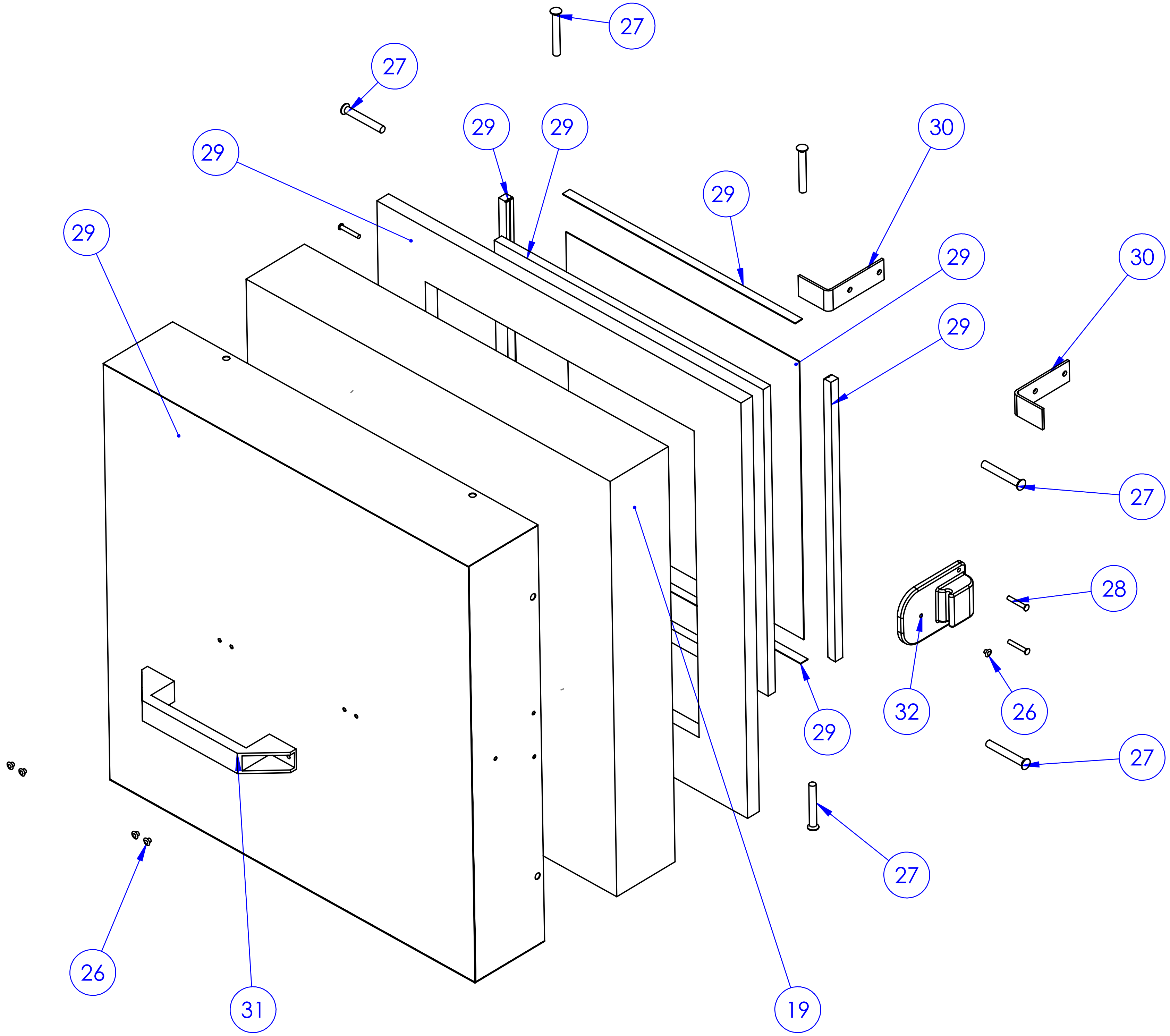
```
hours_per_day = 24; % number of hours in a day
hours_heating = hours_per_day/12; % hours of heating the food/thermal storage
seconds_heating = hours_heating*3600; % seconds of heating the food/thermal storage

% resistance = (outer_r-inner_r)/(4*pi*K*outer_r*inner_r); % resistance for a sphere
% our actual model should be of a cube however to simplify the model a bit
% it was decide to model the resistance as a circle

% Setting up transient model

time_interval = 30; % [sec] interval between readings
duration = hours_heating*3600; % convert hours to seconds
time = [0:time_interval:duration]'; % creates 24 hours worth of data in intervals of 60 secs
time_hours = time/3600; % converts the seconds into hours

delta_temp = zeros(size(time)); % setting up matrix for change of temperature due to time
heat_loss = zeros(size(time)); % setting up matrix for heat loss due to time
energy = zeros(size(time)); % setting up matrix for energy in system for sensible heat due to
time

for i = 1:(numel(time)-1);
    heat_loss(i) = delta_temp(i)/resistance;
    energy(i+1) = energy(i) + (Power_PV - heat_loss(i)) * time_interval;
    delta_temp(i+1) = energy(i+1)/((m_water*c_water)+(m_cement*c_cement));
    if delta_temp(i+1)>= delta_boiling;
        delta_temp(i+1)= delta_boiling;
    end
end

delta_temp2 = zeros(size(time));
heat_loss2 = zeros(size(time));
energy2 = zeros(size(time));

for i = 1:(numel(time)-1);
    heat_loss2(i) = delta_temp2(i)/resistance2;
    energy2(i+1) = energy2(i) + (Power_PV - heat_loss2(i)) * time_interval;
    delta_temp2(i+1) = energy2(i+1)/((m_water*c_water)+(m_cement*c_cement));
    if delta_temp2(i+1)>= delta_boiling;
        delta_temp2(i+1)= delta_boiling;
    end
end
```

Graphs

comparing experimental results to theoretical data

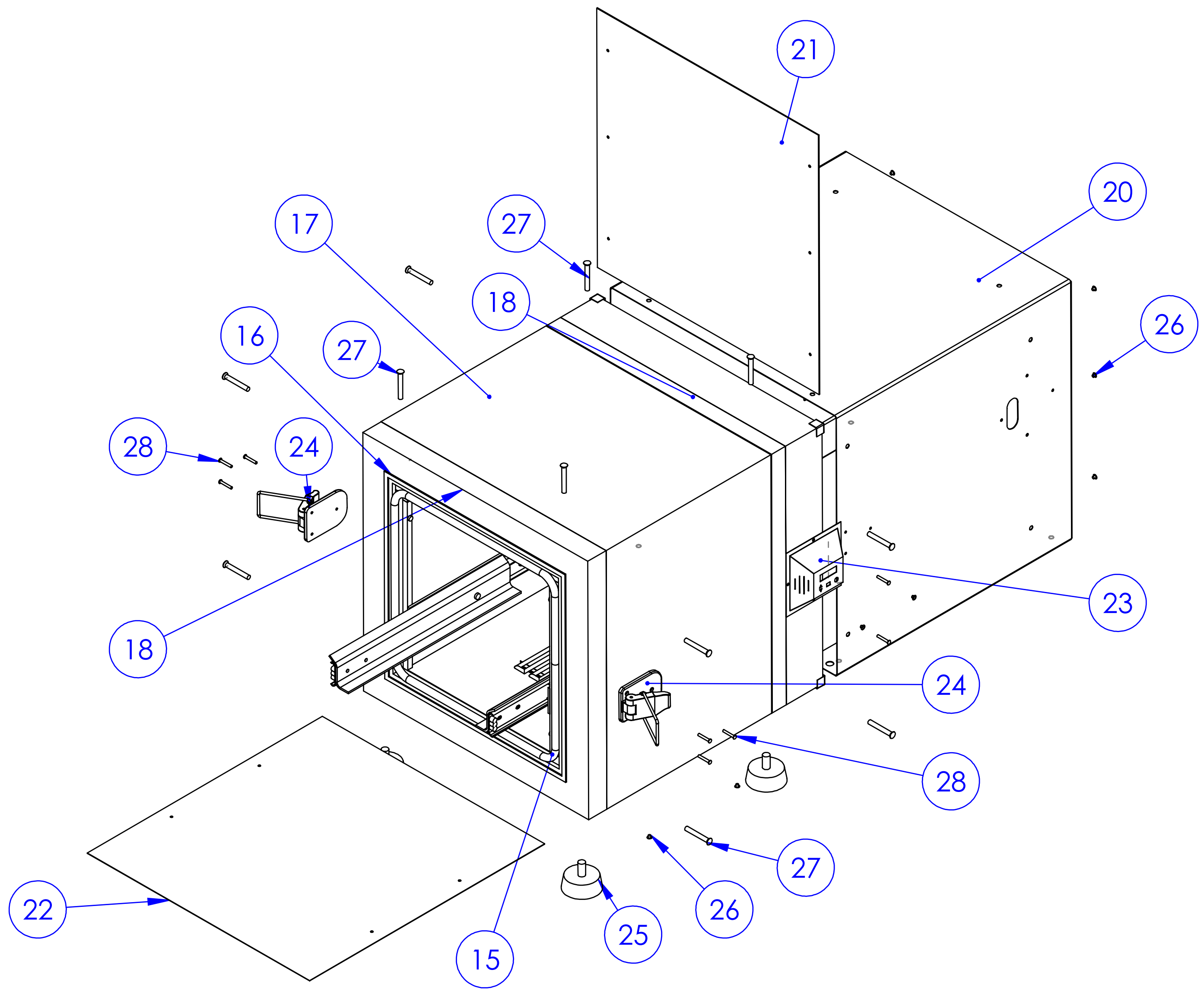
```
figure(1)
plot(time_hours(:,1), (delta_temp(:,1)+amb_temp)*1.8+32, 'red', data(:,1)/60, data(:,2),
time_hours(:,1),(delta_temp2(:,1)+amb_temp)*1.8+32, 'black')
title('Transient model of Cooker')
xlabel('Time [hours]')
ylabel('Temperature [degF]')
ax = gca;
grid(ax,'on')
ax.XMinorTick = 'on';
ax.YMinorTick = 'on';
grid minor
```

Published with MATLAB® R2016a



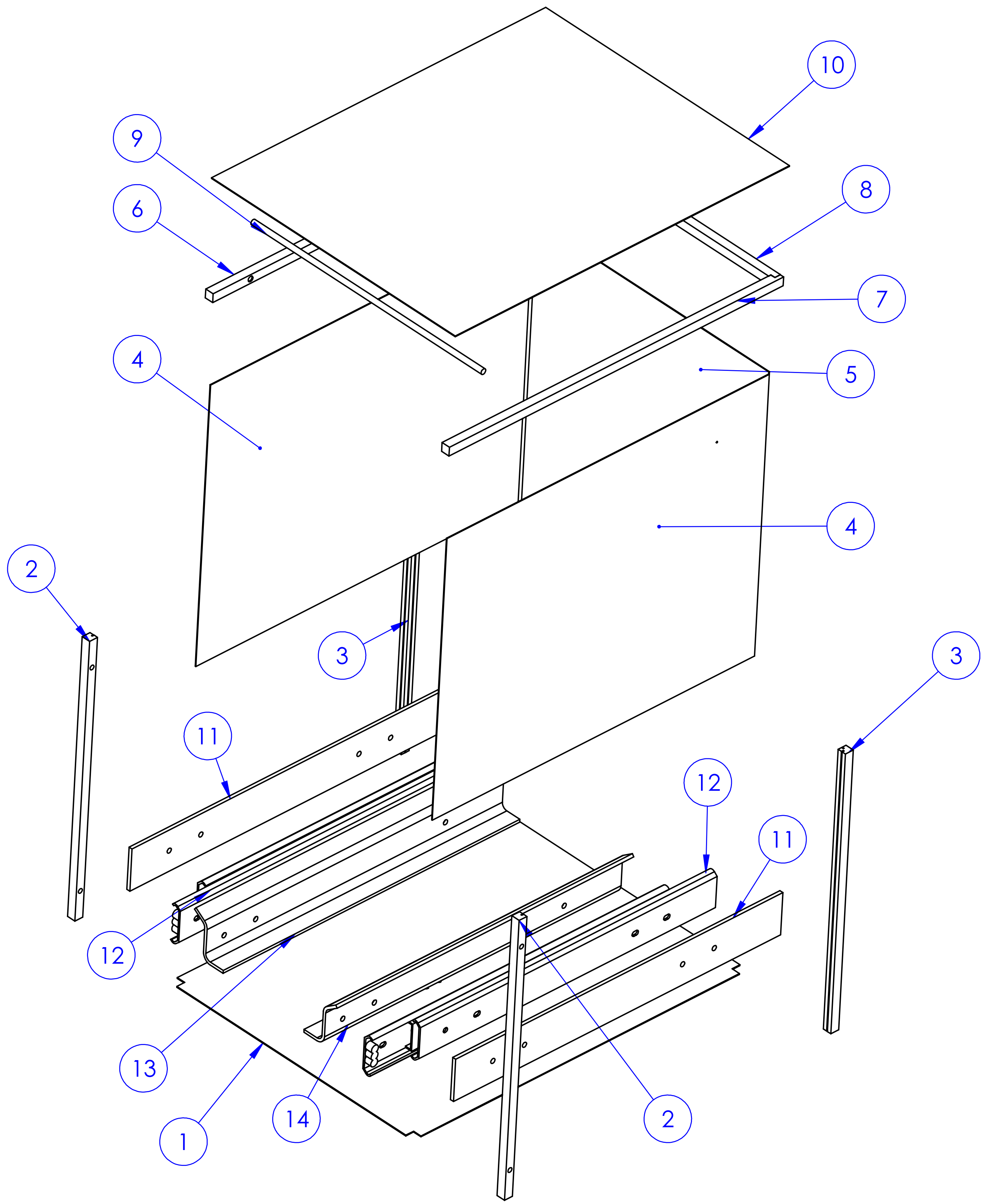
ITEM NO.	Description	Part Number	QTY.
19	Back Wool Insulation	Roxul-R22	1
26	1/8" x 1/8" Pop RivetsB3	24T324	6
27	K40 PT Thread Forming Screws	STAN-PT-K40	8
28	#12-14 Self Drilling Screws	ELC EBL223	4
29	Drawer Outer Box	Draw01	1
30	Steel L-Brackets	SL1	2
31	ABS Plastic Handle	ABS01	1
32	Latch Hook	LT-432	2

Cal Poly Mechanical Engineering ME 429- SPRING 2016	Lab Section:	Assignment #	Title:THREE SIDE SHEET METALL		Drwn. By: Jeff Reeves
	Dwg. #: Draw01	Nxt Asb:	Date: 5/3/16	Scale: 1:4	Chkd. By:



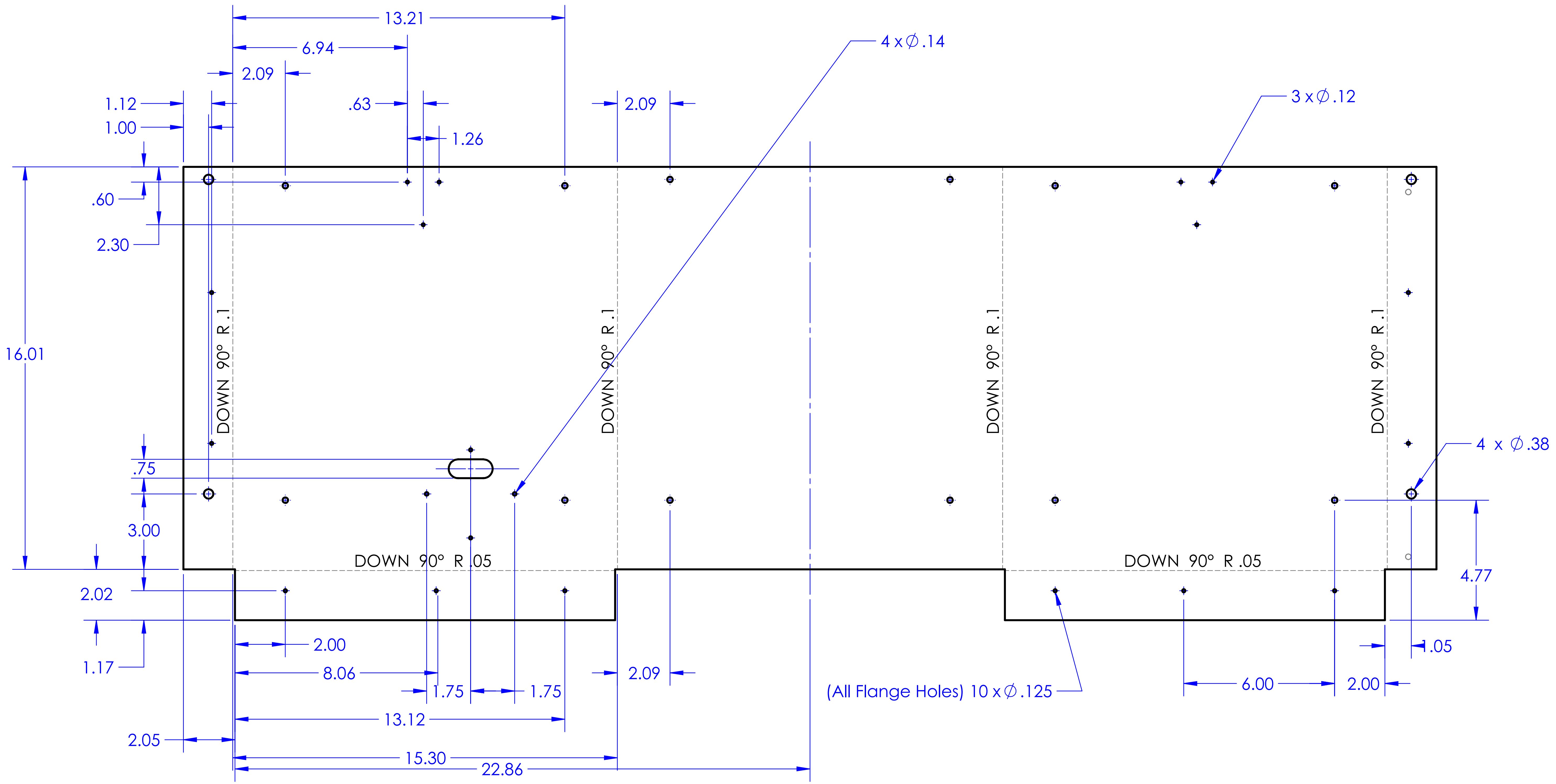
ITEM NO.	Description	Part #	QTY.
15	Inner Gasket	Davlyn-Efiberglass	1
16	Silicon Gasket	71-HT-60D-.032	1
17	Center Wool Insulation	Roxul-R22	1
18	Plastic Support	2A	1
19	Back Wool Insulation	Roxul-R22	1
20	3 Side Sheet Metal	1ABC	1
21	Outer Back Plate	4A	1
22	Outer Floor Plate	5A	1
23	Control Housing	CH-01	1
24	Latch Buckle	LT-431	2
25	Rubber Stand	382DFCFEET	4
26	1/8" x 1/8" Pop Rivet	24T324	12
27	K40 PT Thread Forming Screws	STAN-PT-K40	12
28	#12-14 Self Drilling Screws	ELC EBL223	8
29	Nichrome Wire	NW01	1

Cal Poly Mechanical Engineering ME 429- SPRING 2016	Lab Section:	Assignment #	Title:Outer Box and Components	Drwn. By: Jeff Reeves
	Dwg. #: OutBox01	Nxt Asb:	Date: 5/3/16 | Scale: 1:8	Chkd. By:

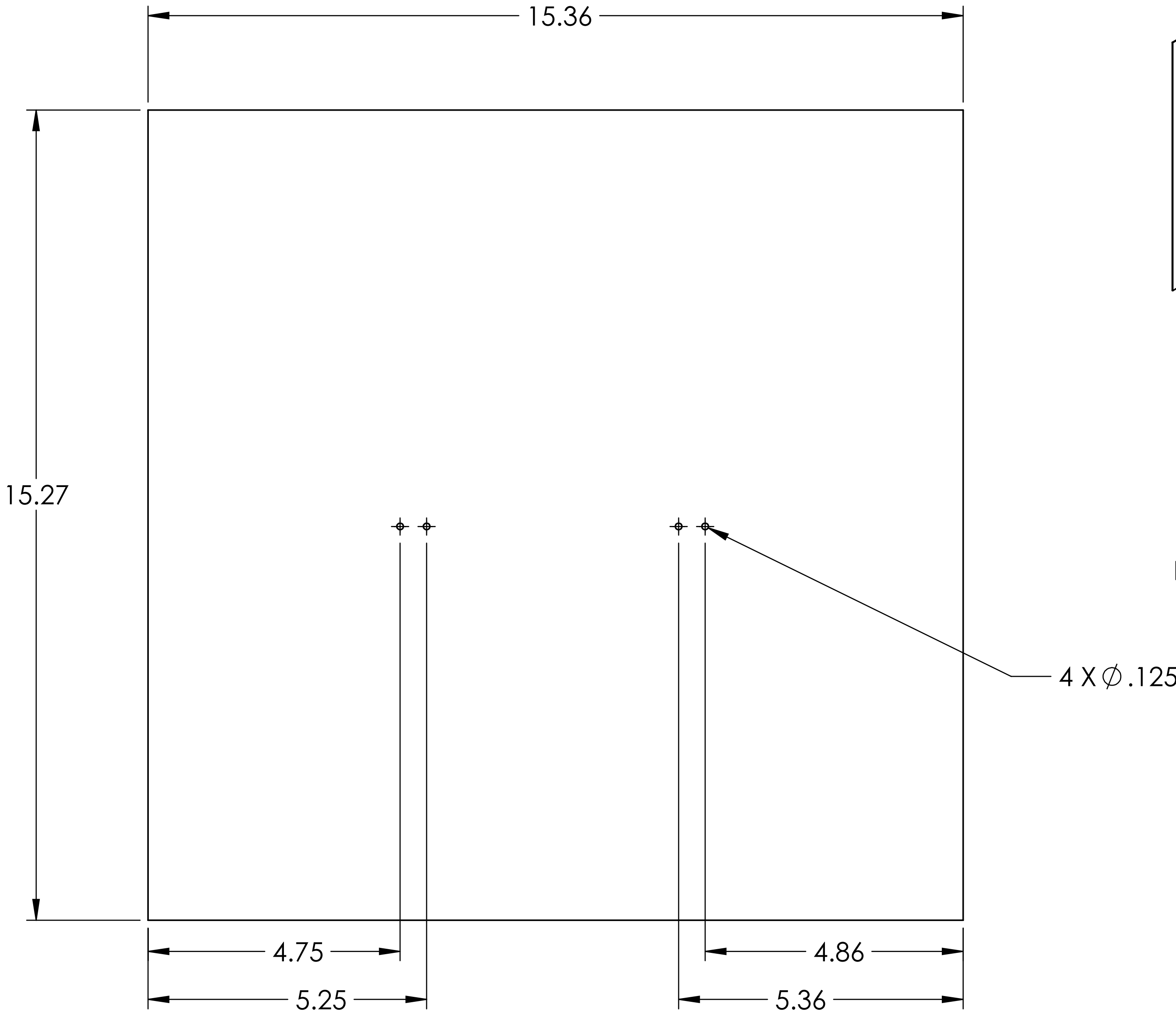


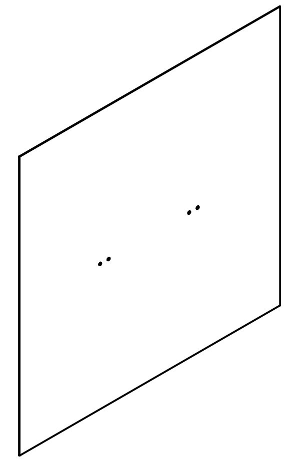
ITEM NO.	Description	Part #	QTY.
1	Inner Bottom Panel	6	1
2	Front Base Supports	3	2
3	Back Base Supports	3	2
4	Inner Side Panels	8	2
5	Inner Back Panel	5	1
6	Inner Top Left Support	11	1
7	Inner Top Right Support	12	1
8	Inner Top Back Support	7	1
9	Inner Top Supporting Bar	4	1
10	Inner Top Panel	9	1
11	Drawer Slide Support	2	2
12	Drawer	SS0330-12	2
13	Drawer Slide Cover Left Side	1C	1
14	Drawer Slide Cover Right Side	1B	1

Cal Poly Mechanical Engineering ME 429- SPRING 2016	Lab Section:	Assignment #	Title:Inner Oven Assembly	Drwn. By: Jeff Reeves
	Dwg. #: AInner01	Nxt Asb:	Date: 5/2/16 / Scale:1:8	Chkd. By:



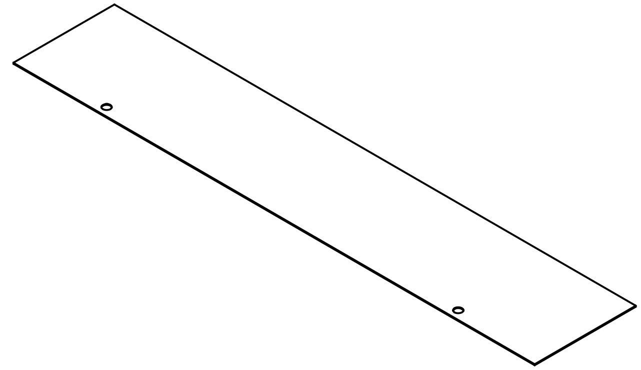
Cal Poly Mechanical Engineering ME 429- SPRING 2016	Lab Section: SP		Title:THREE SIDE SHEET METALL	Drwn. By: PABLO ARROYO
	Dwg. #:1ABC		Date: / Scale: 1-3.75	Chkd. By:



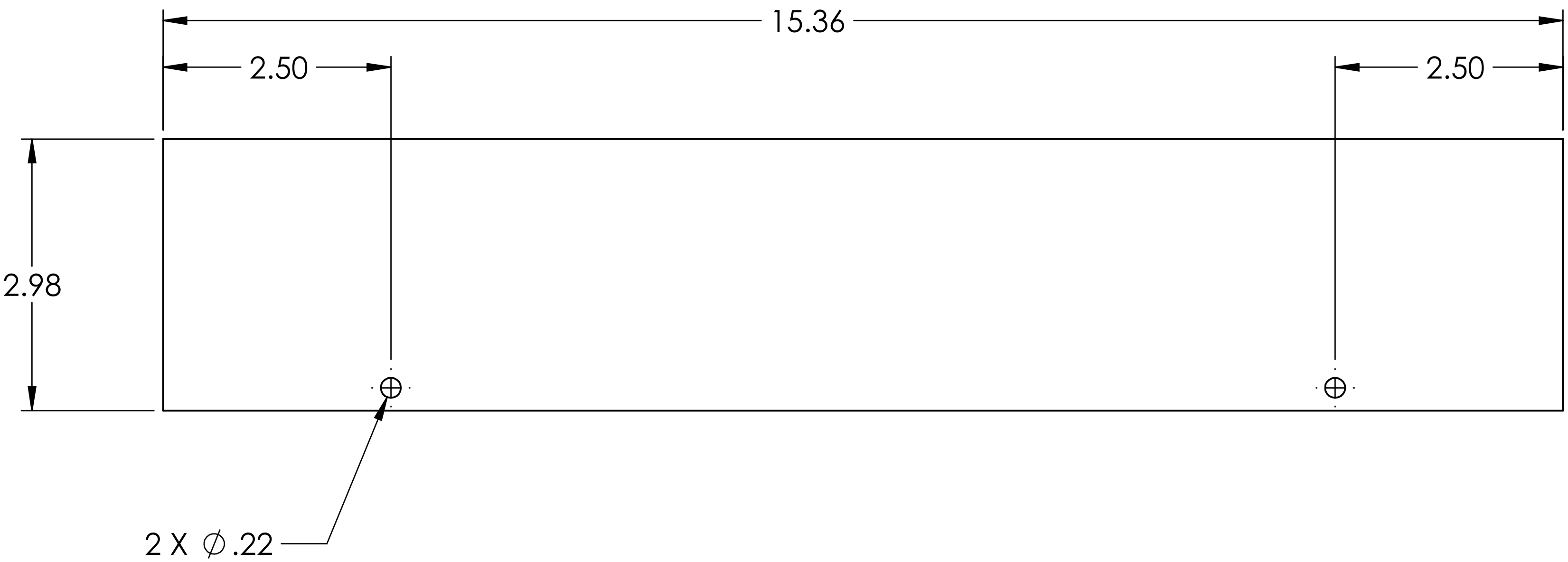


NOTE: THICKNESS 0.025"

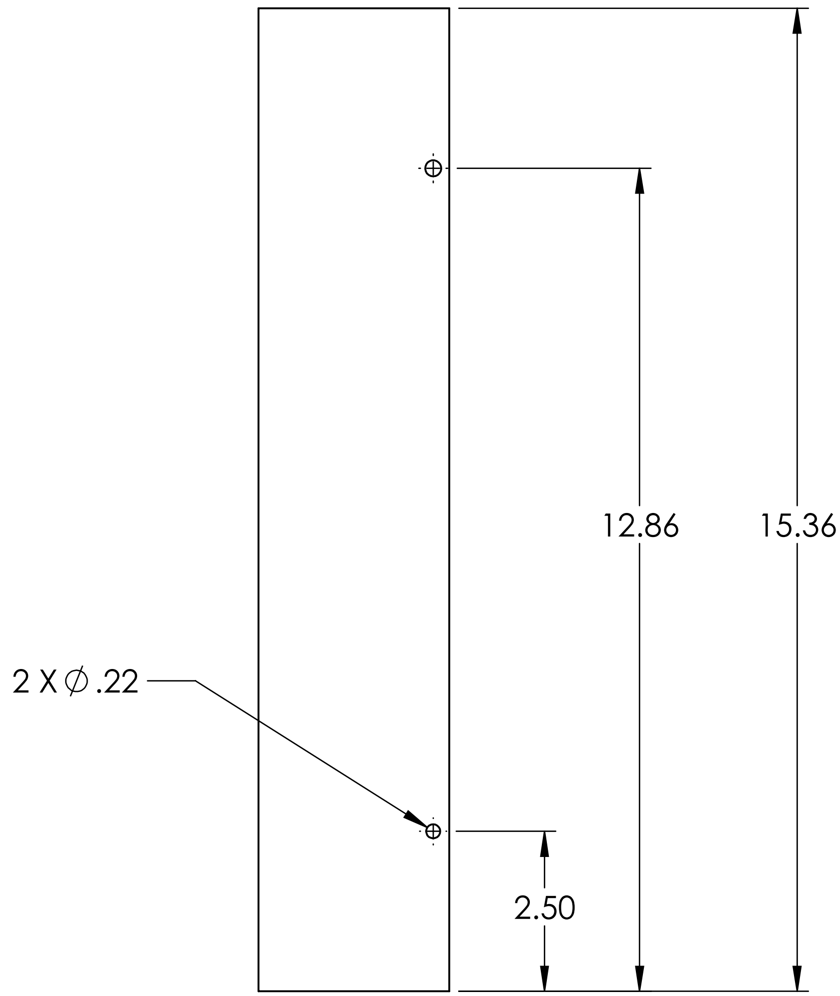
Cal Poly Mechanical Engineering ME 429 - Spring 2016	Lab Section: SPROJECT	Title: BACK DRAWER PANEL	Drwn. By: PABLO ARROYO
	Dwg. #: 1B	Date: MAY 2 / Scale 1-3	Chkd. By:

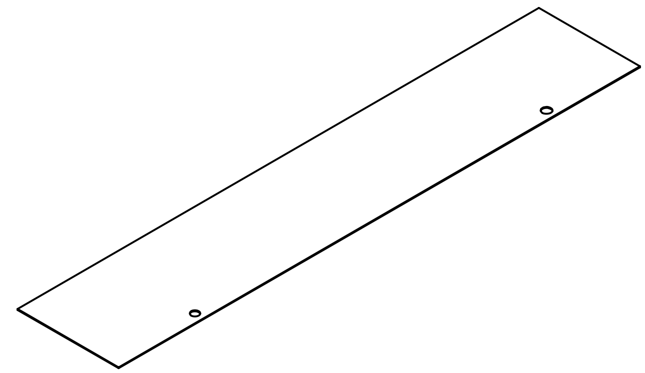


NOTE: THICKNESS 0.025 INCHES



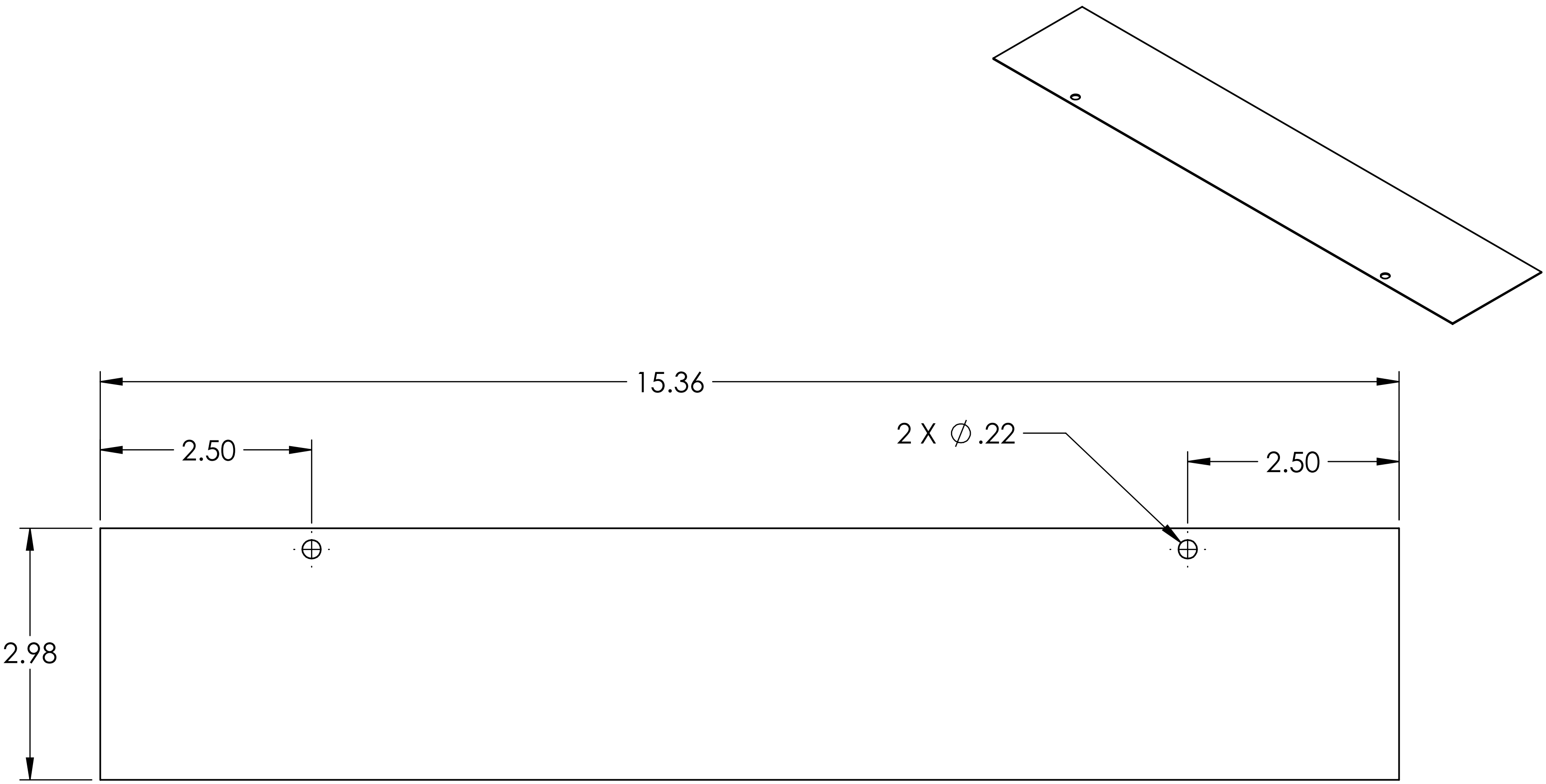
Cal Poly Mechanical Engineering	Lab Section: SPROJECT	Title: BOTTOM DRAWER PANEL		Drwn. By: PABLO ARROYO
ME 429 - Spring 2016	Dwg. #: 4B	Date: MAY 2	Scale 1-2	Chkd. By:



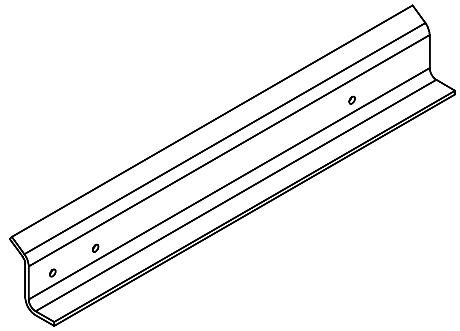


NOTE: THICKNESS 0.025 INCHES

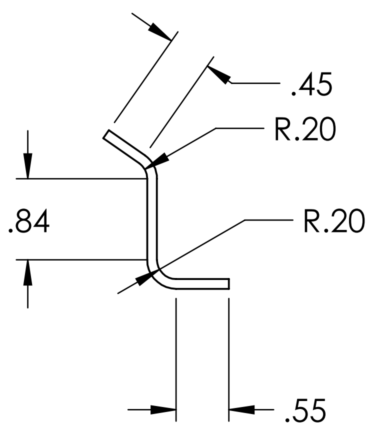
Cal Poly Mechanical Engineering	Lab Section: SPROJECT	Title: TOP DRAWER PANEL		Drwn. By: PABLO ARROYO
ME 429 - Spring 2016	Dwg. #: 8B	Date: MAY 2	Scale 1-3	Chkd. By:

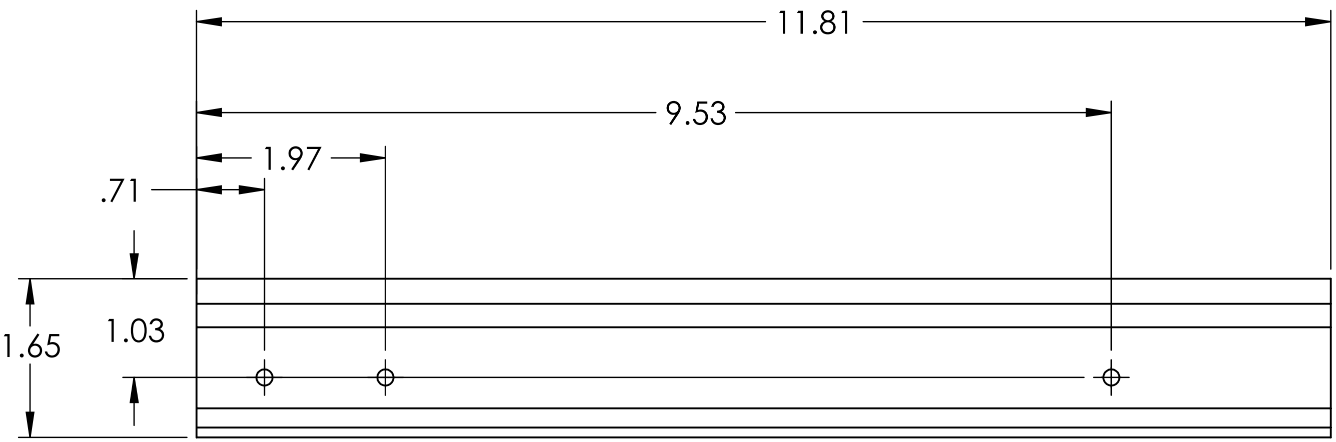


Cal Poly Mechanical Engineering ME 429 - Spring 2016	Lab Section: SPROJECT	Title: DRAWER BOTTOM PANEL		Drwn. By: PABLO ARROYO
	Dwg. #: 2B	Date: MAY 2	Scale 1-2	Chkd. By:

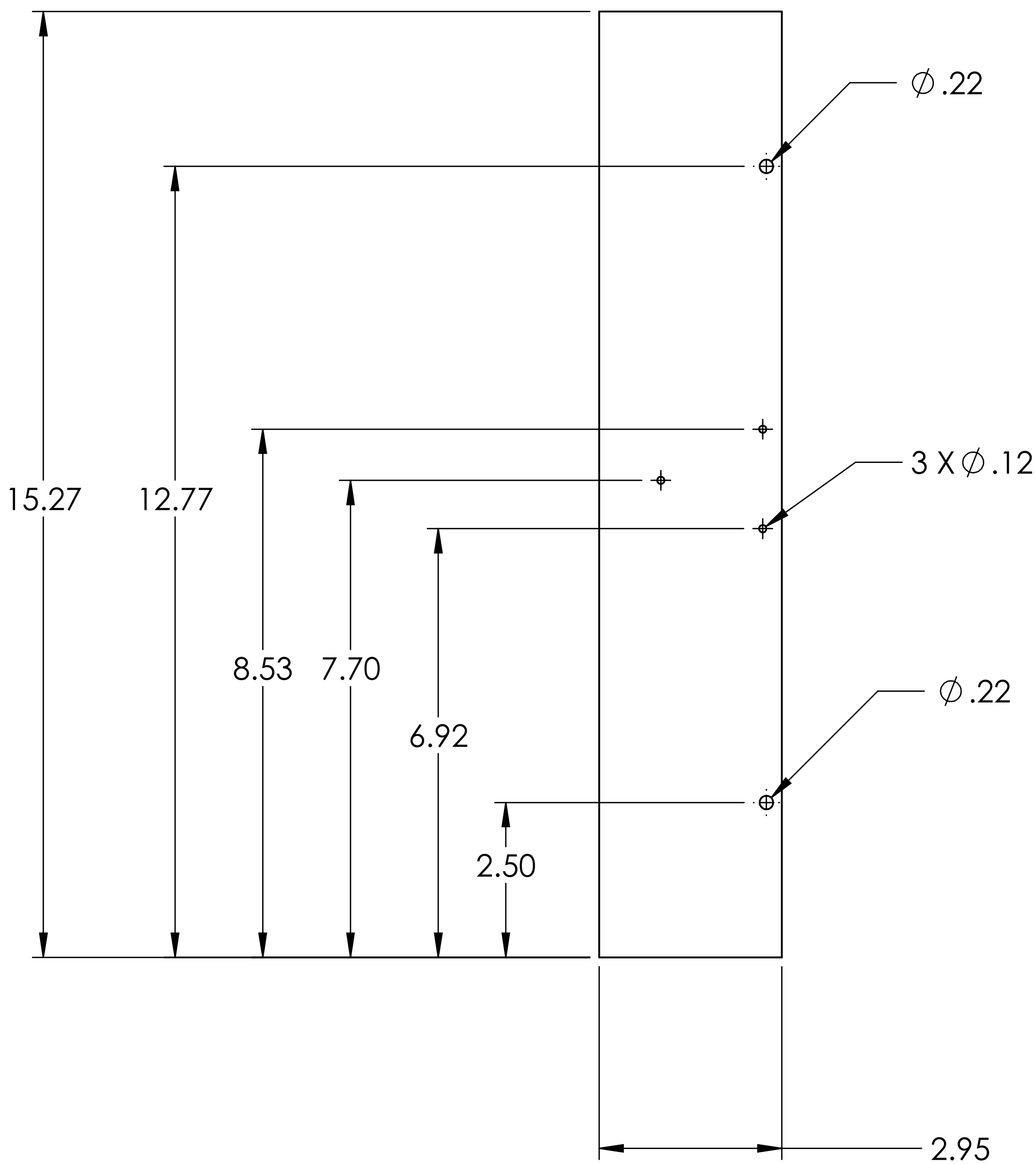


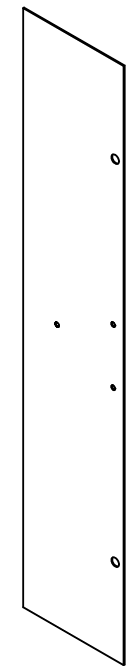
NOTE: ANTOHER MIRRORED IMAGE
SLIDE WILL BE MADE



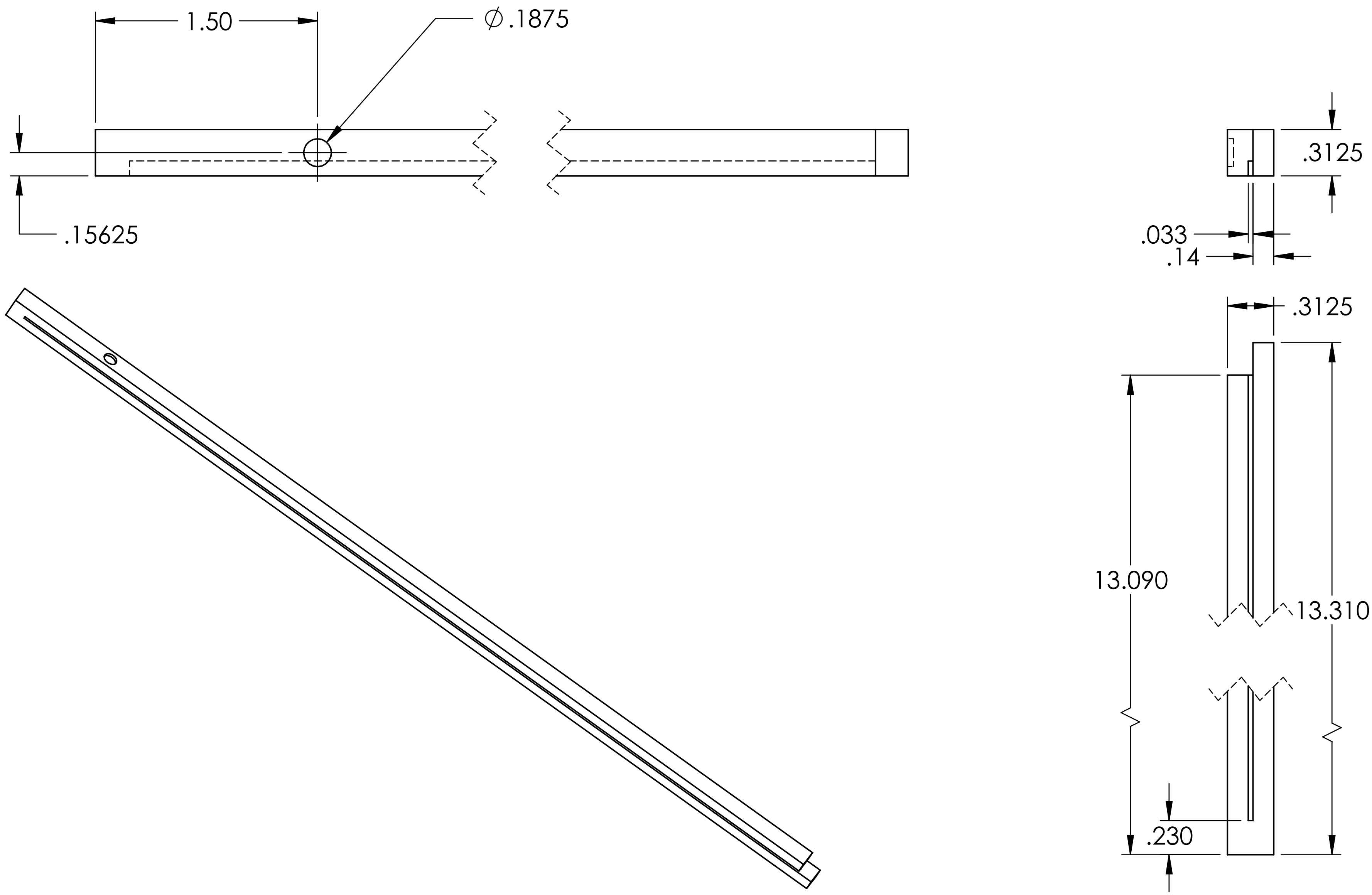


Cal Poly Mechanical Engineering	Lab Section: SPROJECT	Title: DRAWER SLIDE PROTECTORS	Drwn. By: PABLO ARROYO
ME 429 - Spring 2016	Dwg. #: 1C	Date: MAY 2 / Scale 1-2	Chkd. By:

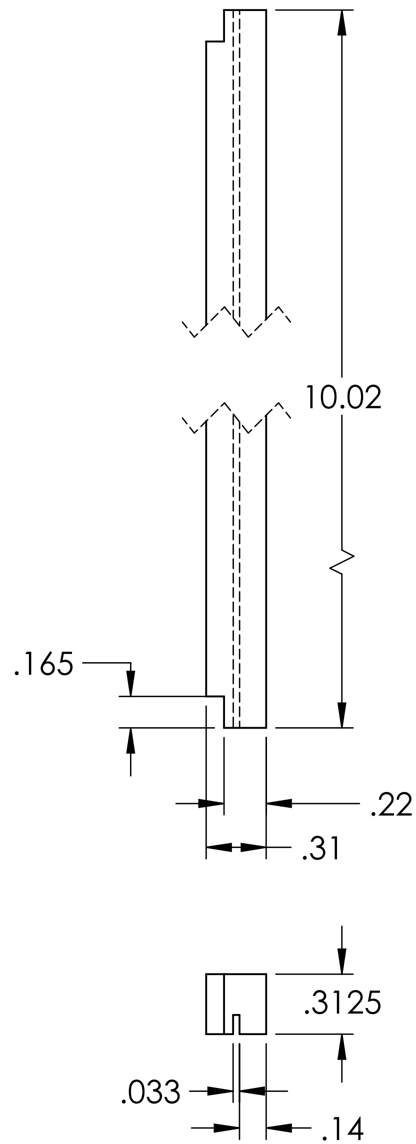


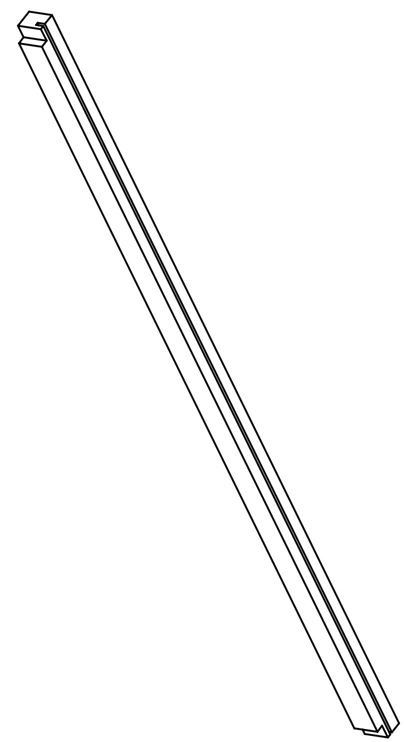


Cal Poly Mechanical Engineering ME 429 - Spring 2016	Lab Section: SPROJECT	Title: DRAWER SIDE PANELS		Drwn. By: PABLO ARROYO
	Dwg. #: 3B	Date: MAY 2	Scale 1-3	Chkd. By:

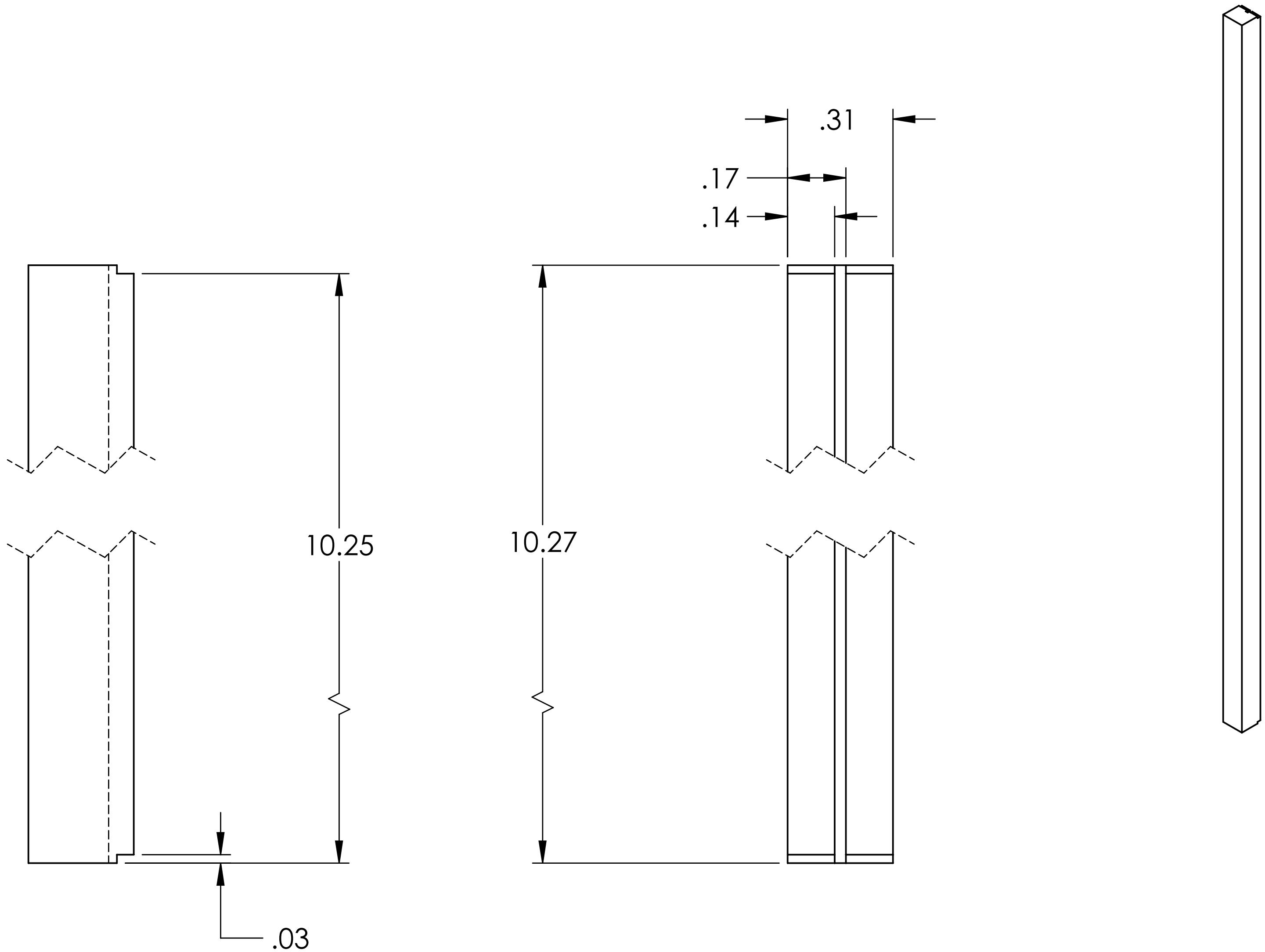


Cal Poly Mechanical Engineering	Lab Section: SPROJECT	Title:INNER TOP LEFT SUPPORT		Drwn. By: PABLO ARROYO
ME 429 - Spring 2016	Dwg. #: 11	Date: MAY 2	Scale 1-1	Chkd. By:

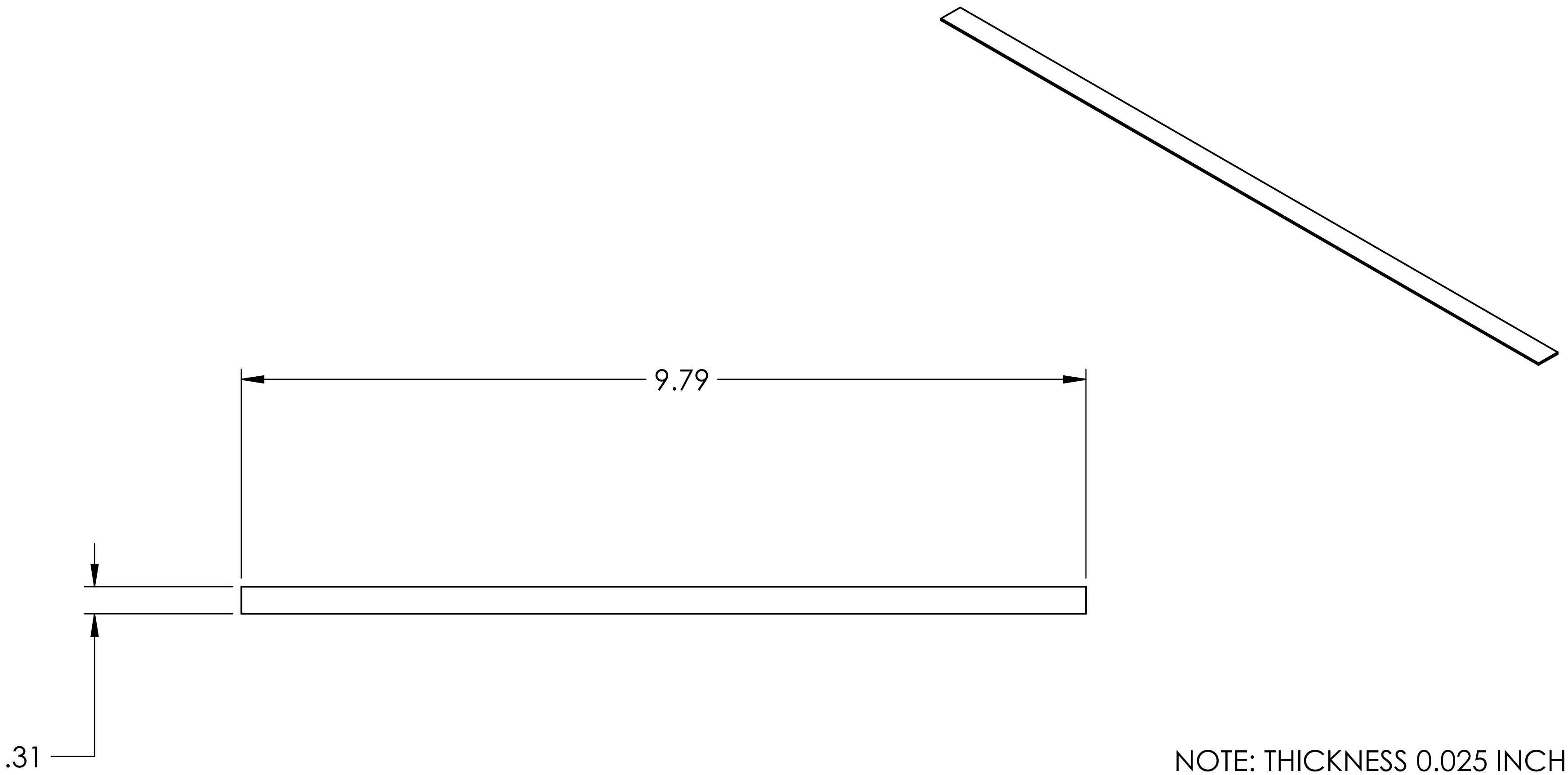




Cal Poly Mechanical Engineering ME 429 - Spring 2016	Lab Section: SPROJECT	Title: INNER OVEN TOP BACK SUPPORT	Drwn. By: PABLO ARROYO
	Dwg. #: 7	Date: MAY 2 / Scale: 1-1	Chkd. By:

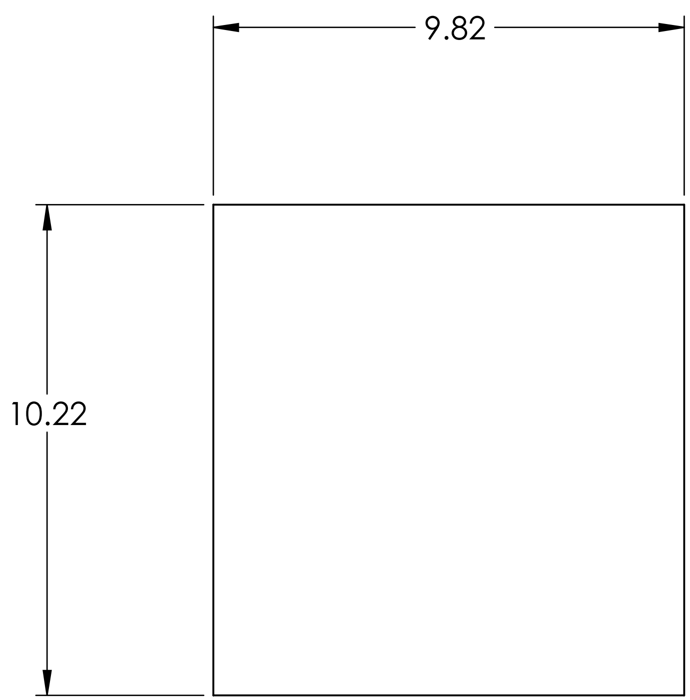


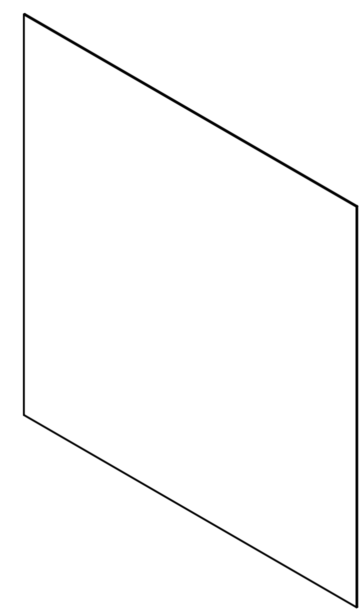
Cal Poly Mechanical Engineering	Lab Section: SPROJECT	Title: DRAWER SUPPORT		Drwn. By: PABLO ARROYO
ME 429 - Spring 2016	Dwg. #: 7B	Date: MAY 2	Scale 2-1	Chkd. By:



NOTE: THICKNESS 0.025 INCHES

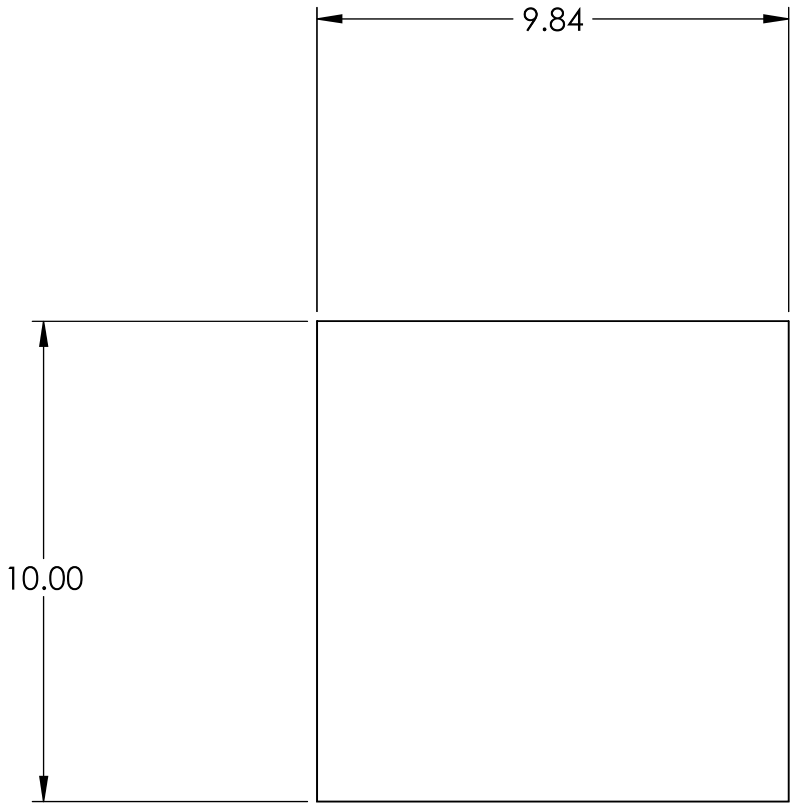
Cal Poly Mechanical Engineering	Lab Section: SPROJECT	Title: THIN DRAWER SHEETS		Drwn. By: PABLO ARROYO
ME 429 - Spring 2016	Dwg. #: 9B	Date: MAY 2	Scale 1-2	Chkd. By:

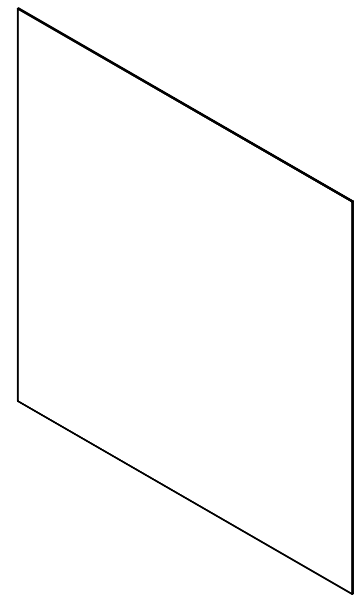




NOTE: THICKNESS 0.025 INCHES

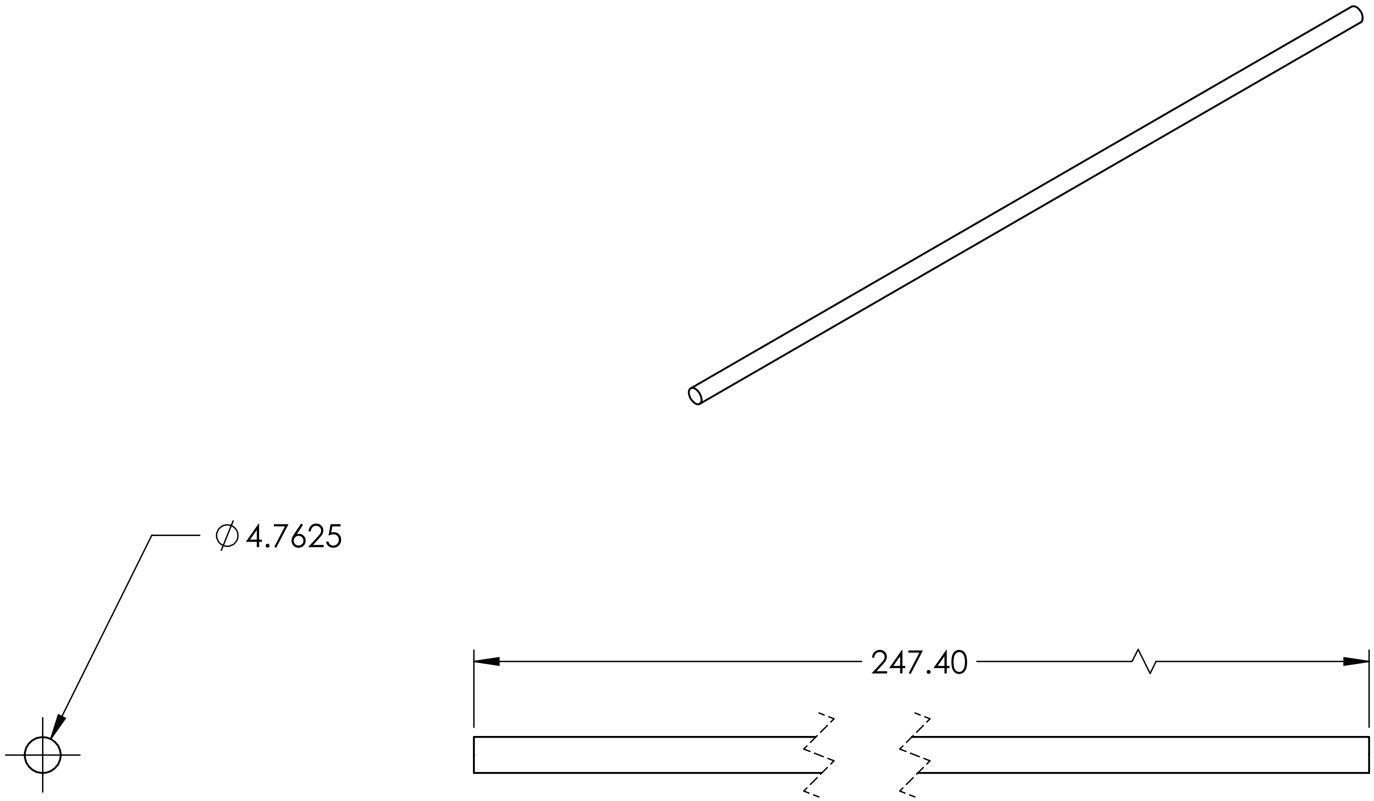
Cal Poly Mechanical Engineering	Lab Section: SPROJECT	Title: FRONT DRAWER PANEL	Drwn. By: PABLO ARROYO
ME 429 - Spring 2016	Dwg. #: 6B	Date: MAY 2 / Scale 1-1	Chkd. By:



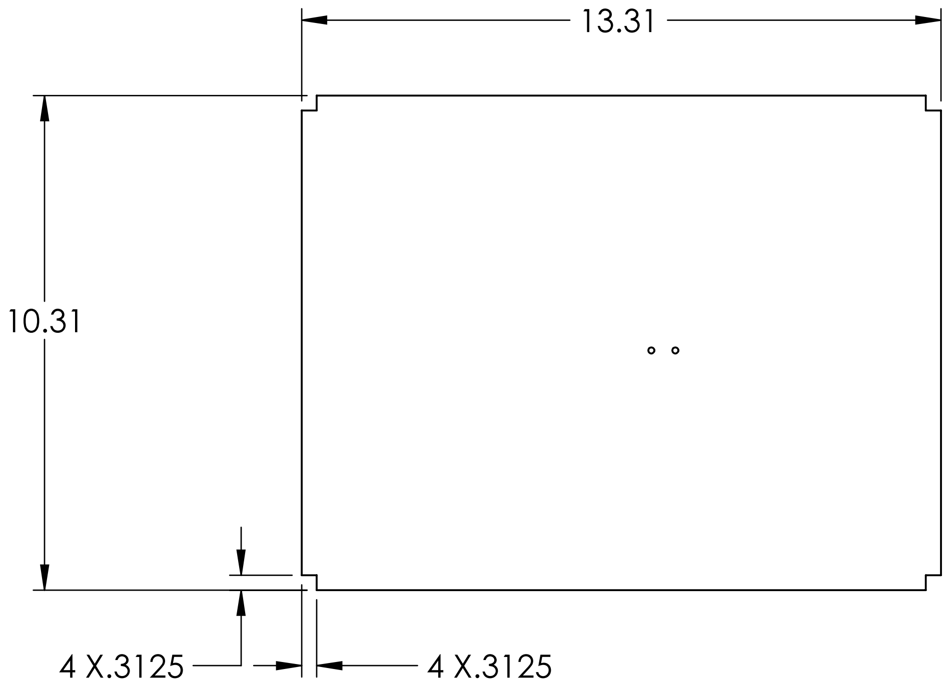


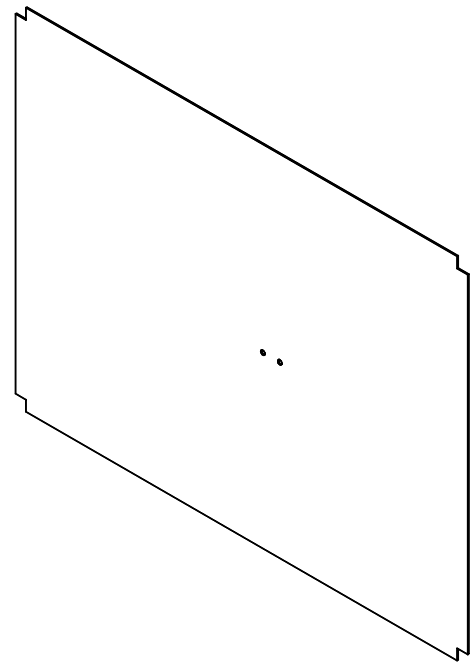
NOTE: THICKNESS 0.025''

Cal Poly Mechanical Engineering	Lab Section: SPROJECT	Title: INNER BACK PANEL		Drwn. By: PABLO ARROYO
ME 429 - Spring 2016	Dwg. #: 5	Date: MAY 2	Scale: 1-4	Chkd. By:



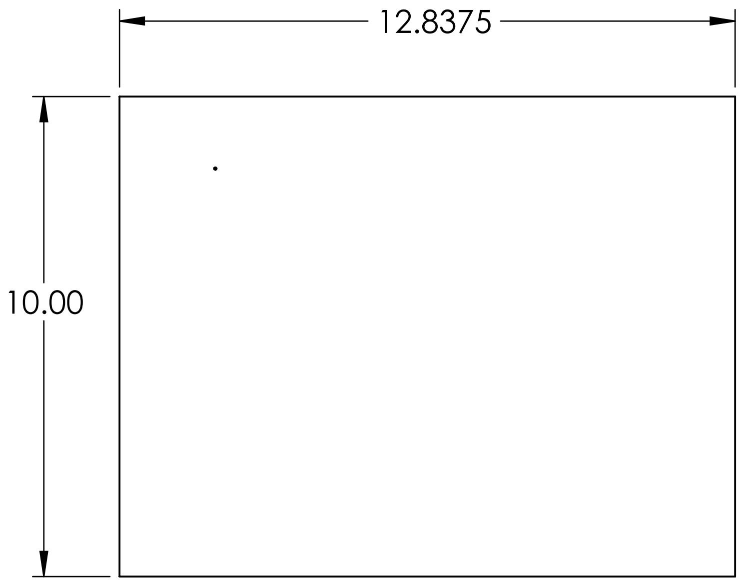
Cal Poly Mechanical Engineering	Lab Section: SPROJECT	Title:INNER OVEN TOP SUPPORT		Drwn. By: PABLO ARROYO
ME 429 - Spring 2016	Dwg. #: 4	Date: MAY 2	Scale:1-1	Chkd. By:

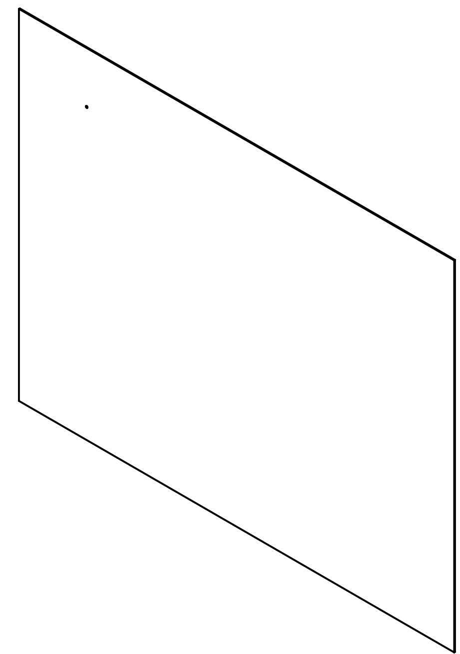




NOTE: THICKNESS 0.025"

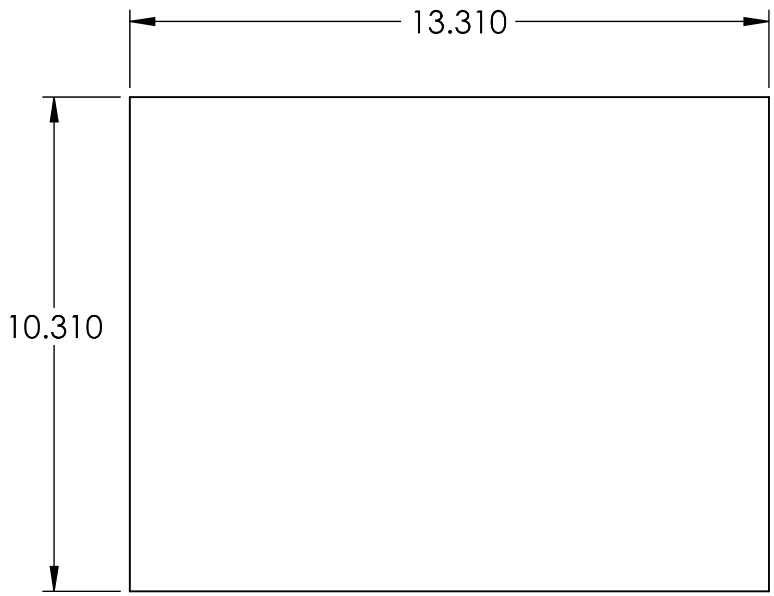
Cal Poly Mechanical Engineering	Lab Section: SPROJECT	Title: INNER BOTTOM PANEL		Drwn. By: PABLO ARROYO
ME 429 - Spring 2016	Dwg. #: 6	Date: MAY 2	Scale:1-4	Chkd. By:

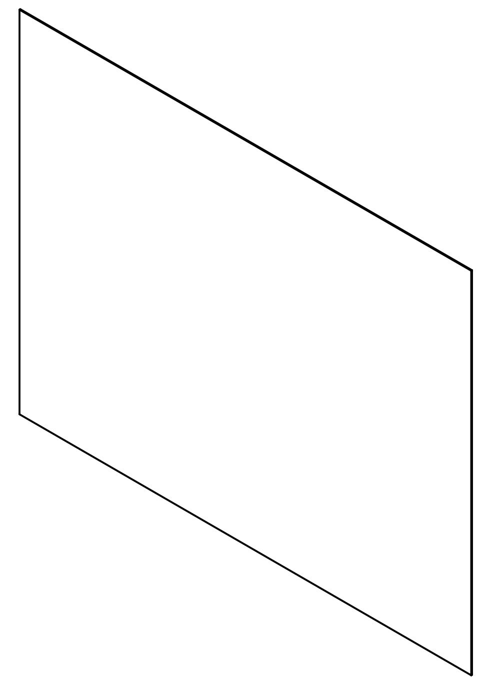




NOTE: THICKNESS 0.025"

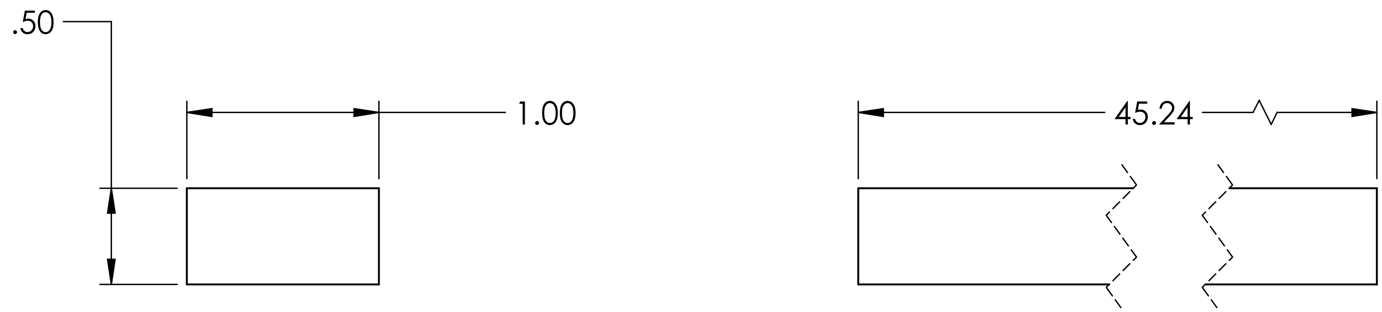
Cal Poly Mechanical Engineering	Lab Section: SPROJECT	Title:INNER SIDE PANELS	Drwn. By: PABLO ARROYO
ME 429 - Spring 2016	Dwg. #: 8	Date: MAY 2 / Scale: 1-4	Chkd. By:

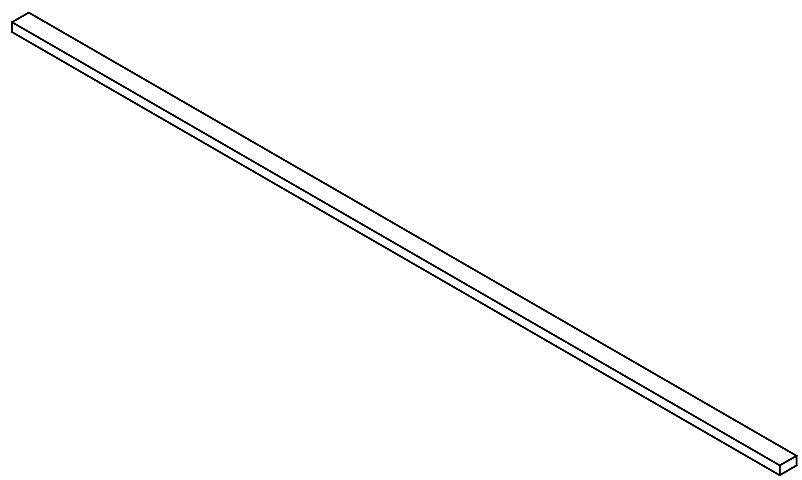




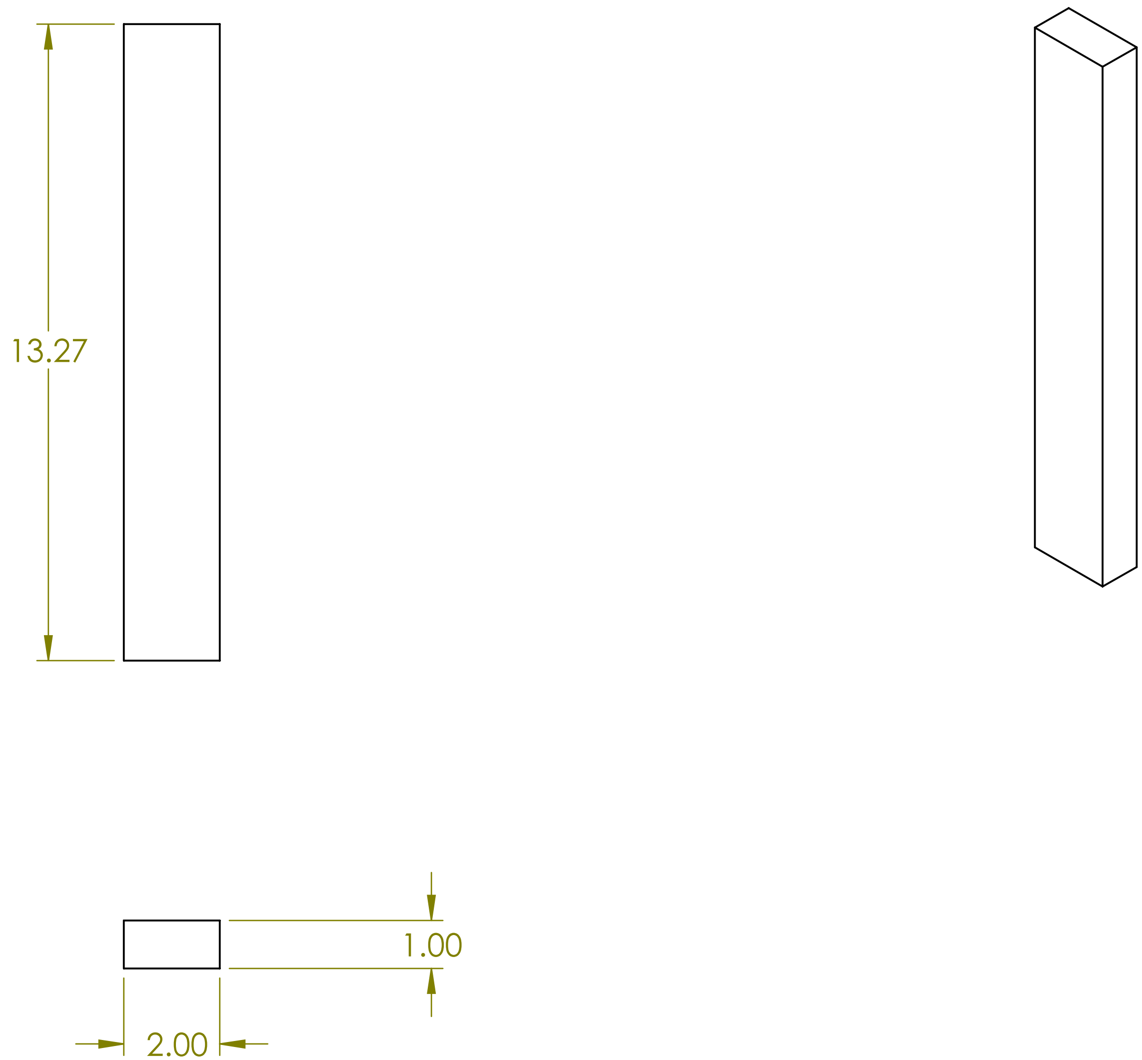
NOTE: THICKNESS 0.025"

Cal Poly Mechanical Engineering	Lab Section: SPROJECT	Title: INNER TOP PANEL	Drwn. By: PABLO ARROYO
ME 429 - Spring 2016	Dwg. #: 9	Date: MAY 2 / Scale:1-4	Chkd. By:

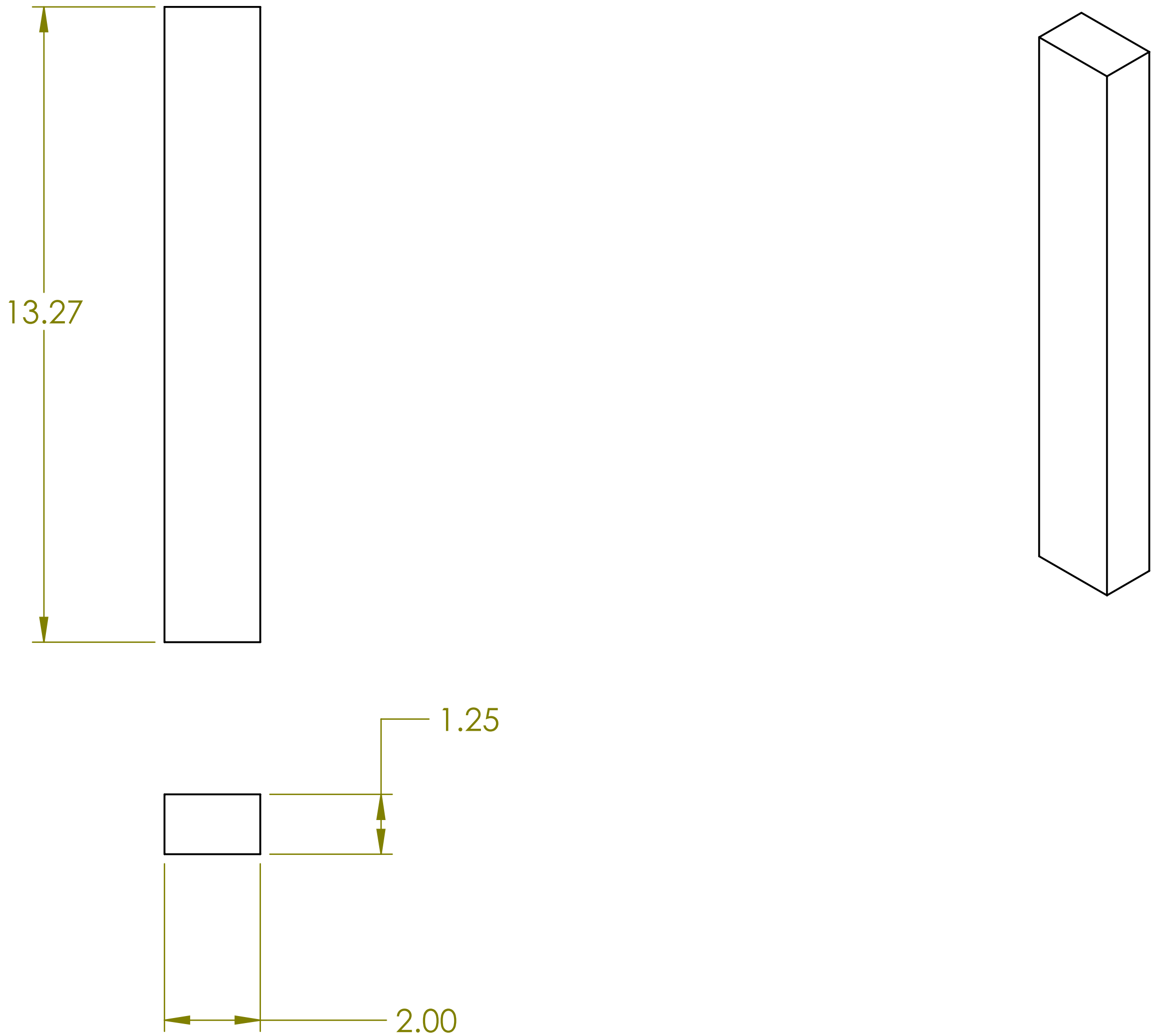




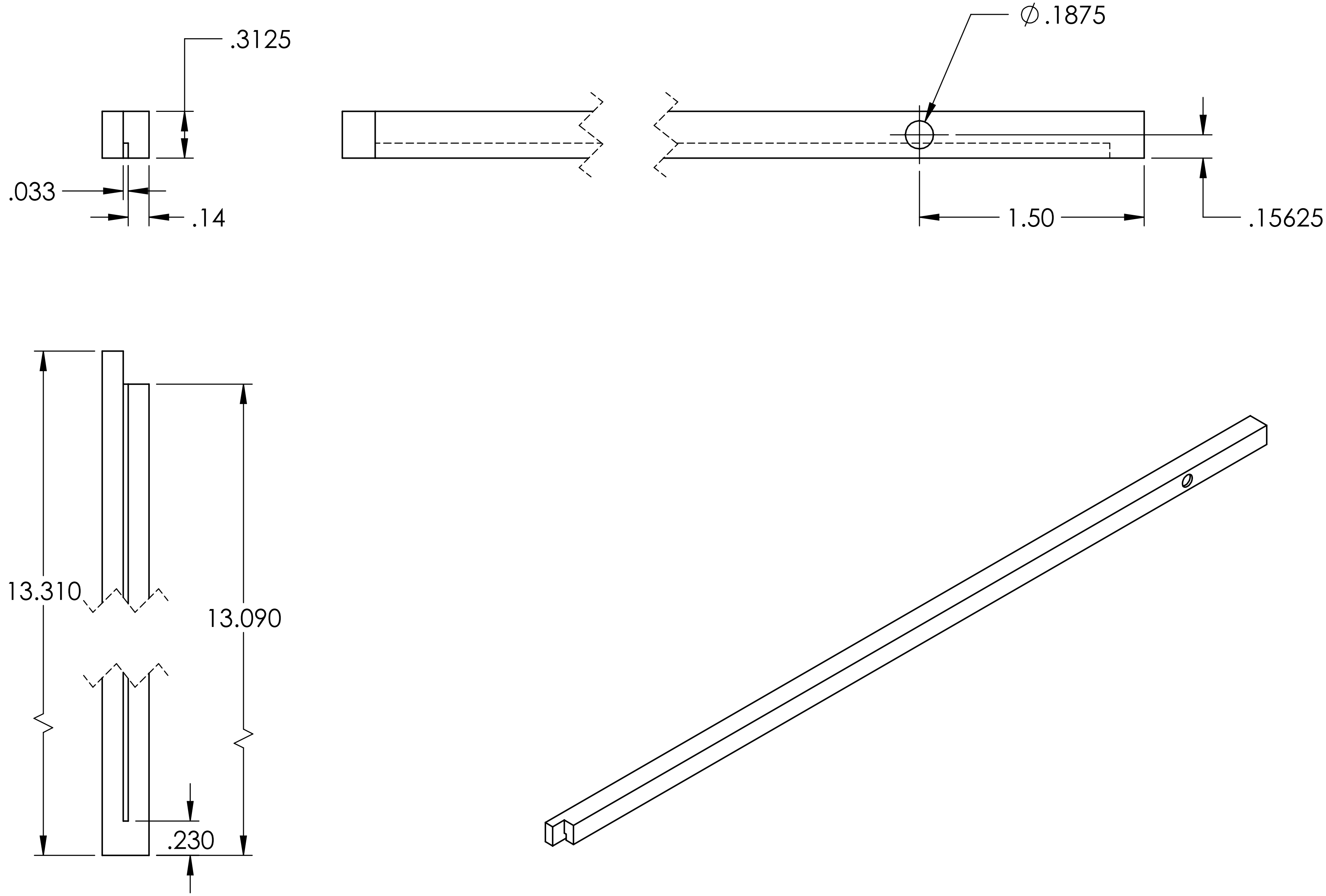
Cal Poly Mechanical Engineering ME 429 - Spring 2016	Lab Section: SPROJECT	Title: MICROTHERM STRIPS	Drwn. By: PABLO ARROYO
	Dwg. #: 1A	Date: MAY 2 / Scale 1-1	Chkd. By:



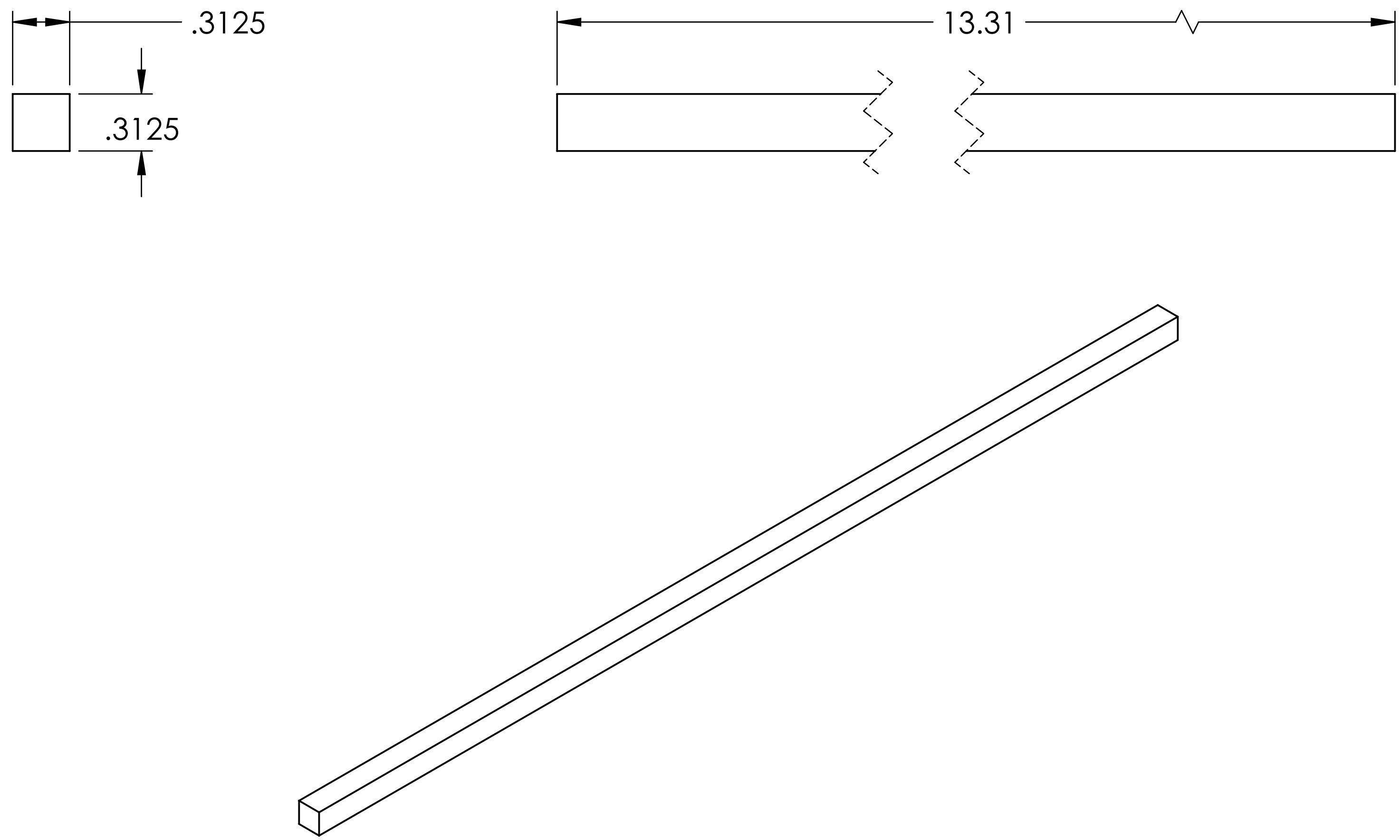
Cal Poly Mechanical Engineering	Lab Section: SPROJECT	Title: PLASTIC SUPPORTS	Drwn. By: PABLO ARROYO
ME 429 - Spring 2016	Dwg. #: 2A	Date: MAY 2 / Scale 1-1	Chkd. By:



Cal Poly Mechanical Engineering	Lab Section: SPROJECT	Title: PLASTIC SUPPORT 2	Drwn. By: PABLO ARROYO
ME 429 - Spring 2016	Dwg. #: 3A	Date: MAY 2 / Scale 1-1	Chkd. By:



Cal Poly Mechanical Engineering	Lab Section: SPROJECT	Title: INNER TOP RIGHT SUPPORT		Drwn. By: PABLO ARROYO
ME 429 - Spring 2016	Dwg. #: 12	Date: MAY 2	Scale 1-1	Chkd. By:



Cal Poly Mechanical Engineering	Lab Section: SPROJECT	Title: INNER TOP SIDE SUPPORT	Drwn. By: PABLO ARROYO
ME 429 - Spring 2016	Dwg. #: 13	Date: MAY 2 / Scale 1-1	Chkd. By: